VOLUME 85 NO. SA4
JULY 1959
PART 1

JOURNAL of the

Sanitary Engineering Division

PROCEEDINGS OF THE

AMERICAN SOCIETY
OF CIVIL ENGINEERS

BASIC REQUIREMENTS FOR MANUSCRIPTS

This Journal represents an effort by the Society to deliver information to the reader with the greatest possible speed. To this end the material herein has none of the usual editing required in more formal publications.

Original papers and discussions of current papers should be submitted to the Manager of Technical Publications, ASCE. Authors should indicate the technical division to which the paper should be referred. The final date on which a discussion should reach the Society is given as a footnote with each paper. Those who are planning to submit material will expedite the review and publication procedures by complying with the following basic requirements:

1. Titles should have a length not exceeding 50 characters and spaces.

2. A 50-word summary should accompany the paper.

3. The manuscript (a ribbon copy and two copies) should be double-spaced on one side of 8½-in. by 11-in. paper. Papers that were originally prepared for oral presentation must be rewritten into the third person before being submitted.

4. The author's full name, Society membership grade, and footnote reference stating present employment should appear on the first page of the paper.

5. Mathematics are reproduced directly from the copy that is submitted. Because of this, it is necessary that capital letters be drawn, in black ink, ⅛-in. high (with all other symbols and characters in the proportions dictated by standard drafting practice) and that no line of mathematics be longer than 6½-in. Ribbon copies of typed equations may be used but they will be proportionately smaller on the printed version.

6. Tables should be typed (ribbon copies) on one side of 8½-in. by 11-in. paper with a 6½-in. by 10½-in. invisible frame. Small tables should be grouped within this frame. Specific reference and explanation should be made in the text for each table.

7. Illustrations should be drawn in black ink on one side of 8½-in. by 11-in. paper within an invisible frame that measures 6½-in. by 10½-in.; the caption should also be included within the frame. Because illustrations will be reduced to 69% of the original size, the capital letters should be ⅛-in. high. Photographs should be submitted as glossy prints in a size that is less than 6½-in. by 10½-in. Explanations and descriptions should be made within the text for each illustration.

8. Papers should average about 12,000 words in length and should be no longer than 18,000 words. As an approximation, each full page of typed text, table, or illustration is the equivalent of 300 words.

Further information concerning the preparation of technical papers is contained in the "Technical Publications Handbook" which can be obtained from the Society.

This Journal is published bi-monthly by the American Society of Civil Engineers. Publication office is at 2500 South State Street, Ann Arbor, Michigan. Editorial and General Offices are at 33 West 39 Street, New York 18, New York. $4.00 of a member's dues are applied as a subscription to this Journal. Second-class postage paid at Ann Arbor, Michigan.

SM,PO,SA.

Journal of the

SANITARY ENGINEERING DIVISION

Proceedings of the American Society of Civil Engineers

CONTENTS

July, 1959

Papers

	Page
Pilot Plants for Water Treatment Research by Gordon G. Robeck and Richard L. Woodward	1
Sludge Treatment and Disposal by the Zimmerman Process Twenty-third Progress Report of the Committee on Sanitary Engineering Research of the Sanitary Engineering Division	13
Dust Properties and Dust Collection by B. Gutterman and W. E. Ranz	25
Operation of a 7-Mile Digested Sludge Outfall by Norman B. Hume, Robert D. Bargman, Charles G. Gunnerson, and Charles E. Imel	71
Absorption of Oxygen from Air Bubbles in Water by W. Wesley Eckenfelder, Jr.	89
Discussion	101

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

PILOT PLANTS FOR WATER TREATMENT RESEARCH

Gordon G. Robeck,[1] M. ASCE and
Richard L. Woodward,[2] M. ASCE

ABSTRACT

The paper outlines the present facilities of pilot plants at the Robert A. Taft Engineering Center and discusses the present studies being carried out and those that are proposed for the future.

Water and sewage treatment pilot plants have been used by the Public Health Service for many years as part of its pollution control research facilities at Cincinnati, Ohio. The pilot plant facilities on which Streeter and his co-workers did their well known studies on the efficiency of water treatment processes in removing coliforms were destroyed due to highway construction in the early 1930's, and from that time until completion of the Robert A. Taft Sanitary Engineering Center no similar equipment was available. However, when the Center was finished in 1953, a large area called the Experimental Wing was provided for pilot plants.

This presentation includes a description of the three water plants in use, and a discussion of the current large-scale studies underway.

Although a variety of specific projects will be undertaken in the future, the overall objective is to review and evaluate present water plant design criteria by operating pilot plants over a wide range of circumstances. Such review may allow for development of new and more effective processes and operating procedures. As new pollutants arise and water shortages increase, it is apparent that both the health and economic factors of supplying adequate and safe water do need reappraisal.

Note: Discussion open until December 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2086 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. SA 4, July, 1959.

1. Sr. San. Engr., Robert A. Taft Sanitary Eng. Center, Public Health Service, Dept. of Health, Education, and Welfare, Cincinnati, Ohio.
2. San. Engr. Director, Robert A. Taft San. Eng. Center, Public Health Service, Dept. of Health, Education, and Welfare, Cincinnati, Ohio.

Present Facilities

The wing housing the pilot plants is 80 by 45 feet, and the overhead, 5-ton bridge crane allows for approximately 25 feet of vertical clearance. About one-half of this space is used for the water plants, while the other half is used for sewage treatment plants and bioassay apparatus. The recirculating air and heating system is separate from the rest of the Center. Open, 650-gallon surge tanks are provided near the ceiling to handle incoming Cincinnati tap water and raw river water.

The pilot plants vary in size. That used for the study of individual home treatment units is full scale at 1/3 gallon per minute, whereas the two other plants which are used for studying conventional municipal needs operate at approximately 0.3 liter/minute and 16 gpm.

These sizes were dictated largely by available space and water, but in general the large plant was designed to study operational problems and the influence of major structural changes. It is made of a cypress wood and ordinary structural steel and necessarily uses an inexpensive raw river water. The small 0.3 liter/minute plant was designed to study more closely the various individual phenomena that influence the success of treatment, particularly in filters. It uses a highly controlled synthetic water and is made of transparent plastic and stainless steel. Experiments with hazardous, scarce, or expensive contaminants are more practically done in this small plant.

The horizontal and vertical dimensions of the pilot plant tanks are not all scaled down in proportion. Instead, the design for the flash-mix and flocculation tank is based on detention time, and for the settling tank and filters on surface area and overflow rate. However, consideration has been given to the ratio of length to width or to depth of tank so that the proportioning of the larger plant units is similar to that of a conventional plant. In any case, the materials of construction and size of pumps, etc. are such that after the duplicate plants of conventional design give comparable results, departures in design can be made in one plant while the other is maintained as usual.

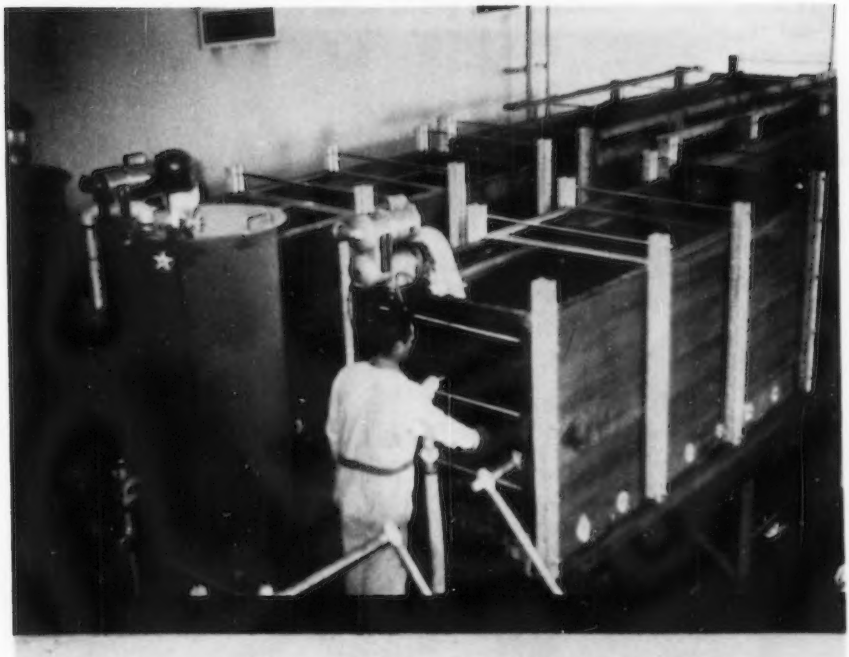
16-GPM Pilot Plant

In the case of the 16-gpm pilot plant, the actual detention time in the 100-gallon, 2-foot diameter, flash tank can be varied from a few seconds to 10 minutes by raising or lowering the tank. (See Figure 1)

A 1/8-HP high-speed mixer quickly disperses the coagulant and other chemicals that are fed by a small diaphragm pump from a 30-gallon polyethylene stock tank.

The 1000-gallon, 10-foot × 3.5-foot × 4-foot flocculation tank which then receives the water has a theoretical detention time of 55 minutes for a normal filter plant rate of 2 gpm/sq. ft. The degree of gentle mixing is varied by the number and size of paddles and the speed of the mixer. A vertical baffle at the center reduces short circuiting so that the first trace time with dye is 4 minutes and the actual flow through time is about 40 minutes.

The 3-inch discharge pipe is near the bottom of the flocculation tank but enters closer to the center of the bigger 3300-gallon settling tank. A baffle box with a diverging throat is used to direct the water and floc up and uniformly across this tank which is 4 feet wide, 18 feet long, and 6 feet deep. At a normal rate, the theoretical detention time in this tank is about 3.5 hours;



TWO 16-GPM PILOT PLANTS SHOWING FLASH MIXERS, FLOCCULATORS, AND SETTLING TANKS

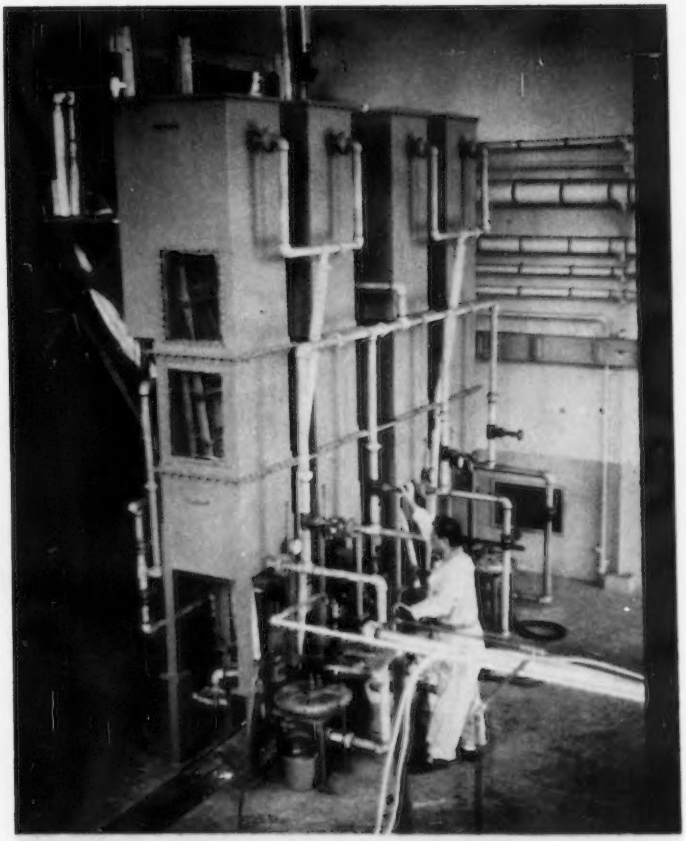
FIGURE 1

however, the first dye-trace time is about 6 minutes, and an actual flow through takes approximately 1 hour. The overflow rate is 320 gallon/sq. ft./day. The discharge to the filters is into a v-notched weir channel across the tank, 2 feet from the end.

The flow from each settling tank is divided to go to two filter columns. Each of these 2-foot × 2-foot × 10-foot columns has a glazed filter block at the bottom and various depths of gravel and sand, or other filter media. Initially, 2 feet of uniform-sized Muscatine, Iowa, sand and 18 inches of graded gravel are being used. A backwash water pump supplies as much as 120 gpm and provisions are being made to have a surface wash. Air backwashing facilities will be installed later. The rate of flow through the filter is controlled by a pressure regulator and interchangeable orifice plates. One column wall has a 4-foot long observation window of clear plastic. (See Figure 2).

Two pH indicators and recorders are placed in the raw and finished water.

The raw water for these plants is pumped from the Little Miami River, a distance of approximately 1.5 miles, in a 4-inch steel pipe and raised about 150 feet to an open surge tank in the Center's Experimental Wing. This tank handles the constant incoming flow of 100 gpm, which allows the two pilot plants to operate at any rate up to 2 or 3 times the normal rate of 16 gpm.



FOUR 2'x 2' FILTER COLUMNS
WHICH FOLLOW THE SETTLING TANKS

FIGURE 2

Excess water overflows to the sewer. The river is a small, flashy tributary of the Ohio River and during floods is subject to backwater from the Ohio River which is only 2 to 3 miles away from the intake.

0.3 Liter/Minute Pilot Plant

The 0.3 1/min. plexiglass pilot plant is set up in triplicate with 2 filter columns handling the water from each plant. The makeup water is carefully prepared by demineralizing it in a mixed-bed ion-exchanger, storing it to equalize temperature, and clarifying it in a cartridge-type pressure filter. When organisms are to be the contaminant, chlorine in the form of Clorox is added to disinfect the supply and the entire system, and then sodium thiosulfate

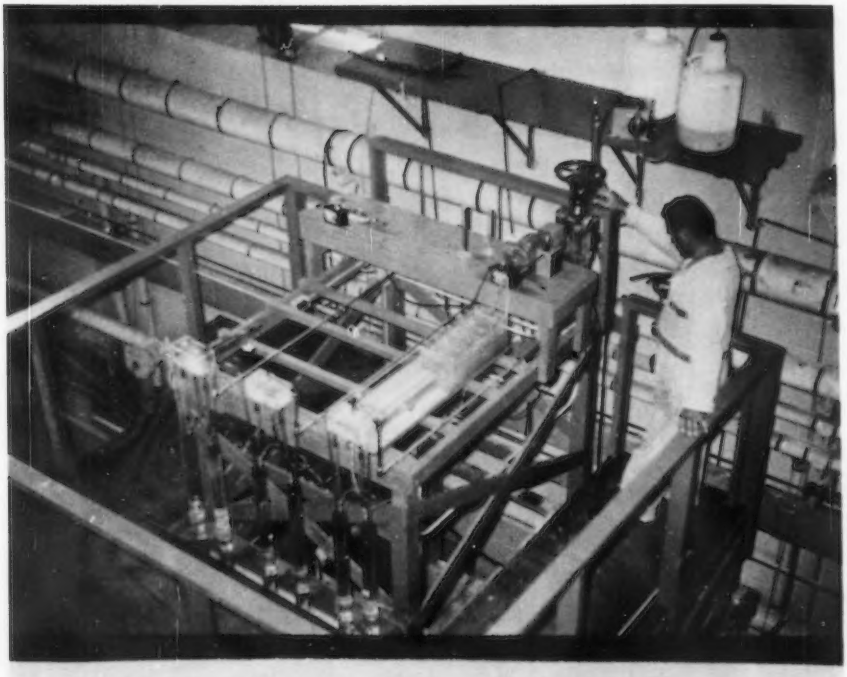
is added to dechlorinate just before adding the contaminant. (See Figure 3).

This preparation permits a known quantity of physical, chemical, or biological contaminant to be added to the raw water and subsequently to the treatment plant, and is particularly necessary when doing experiments with clean water on clean sand.

Diaphragm pumps with variable discharge adjustments are used to lift the water to a rapid mix where coagulants are added. The average detention time can be varied in this unit, but it is usually only a minute or two.

The flocculation units are 12-inches × 6-inches × 6-inches, with a theoretical detention time of 30 minutes. Mixing is done with the usual slow-moving paddles of varying sizes. Their speed can be varied considerably. The settling tanks, with 21-inch × 6-inch × 6-inch dimensions, are overdesigned so as to be able to apply a more typical water to the filters. At conventional overflow rates, clarification is poor since it is impossible to scale down the velocities as well as the dimensions. Hence, inlet baffling and outlet weirs influence a high percentage of the tank capacity. Thermal differences cause density current which impair settling also.

The 2-inch filter columns have a capacity to handle any depth of media up to 36 inches and still allow room for backwashing. Twenty-four inches of



TOP VIEW OF 0.3–GPM PILOT PLANT
MADE OF CLEAR PLASTIC

FIGURE 3

Ottawa sand is being used at the present time. Although graded gravel is used at the bottom to aid in distributing backwash water, the filter media is supported by a 100-mesh stainless steel screen to prevent the usual mixing of fine gravel and sand. (See Figure 4).

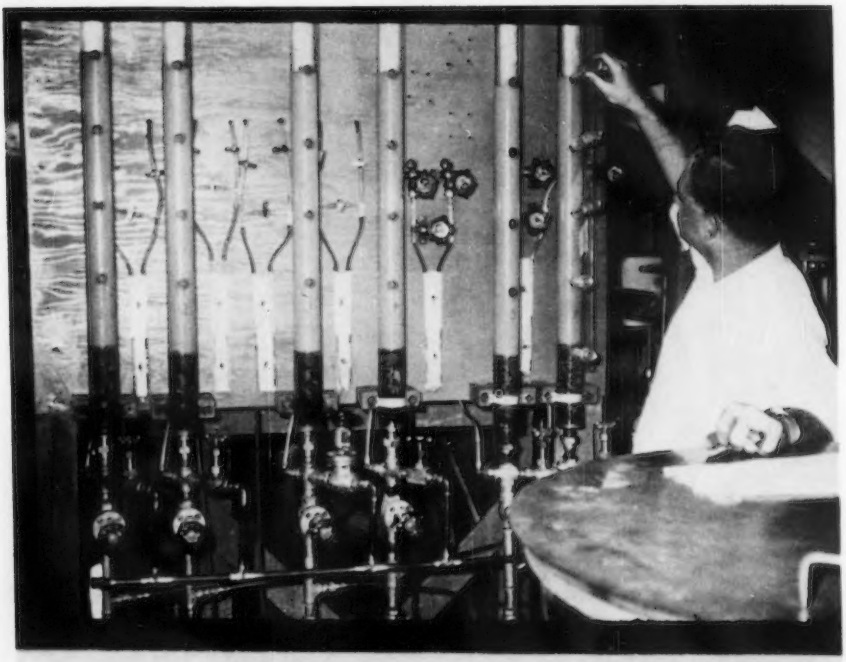
A 2-inch diameter was selected for these columns to minimize wall effects. Other studies have indicated that as long as the column diameter is 50 times larger than the media particle the filtration would be the same as in a full-scale filter.

The flow rate through the filter is controlled by pumping from the bottom of the column with a high precision gear pump. This arrangement allows for a flow variation from 1 to 660 ml/minute, or a rate range of 0.01 to 8 gpm/sq. ft.

Special ports of self-sealing rubber placed at 6-inch intervals along the column allow for sampling at points above, within, or below the bed. A 30-ml syringe with a 3/4-inch, #23 needle will slowly draw off samples when injected through the rubber port. (See Figure 5).

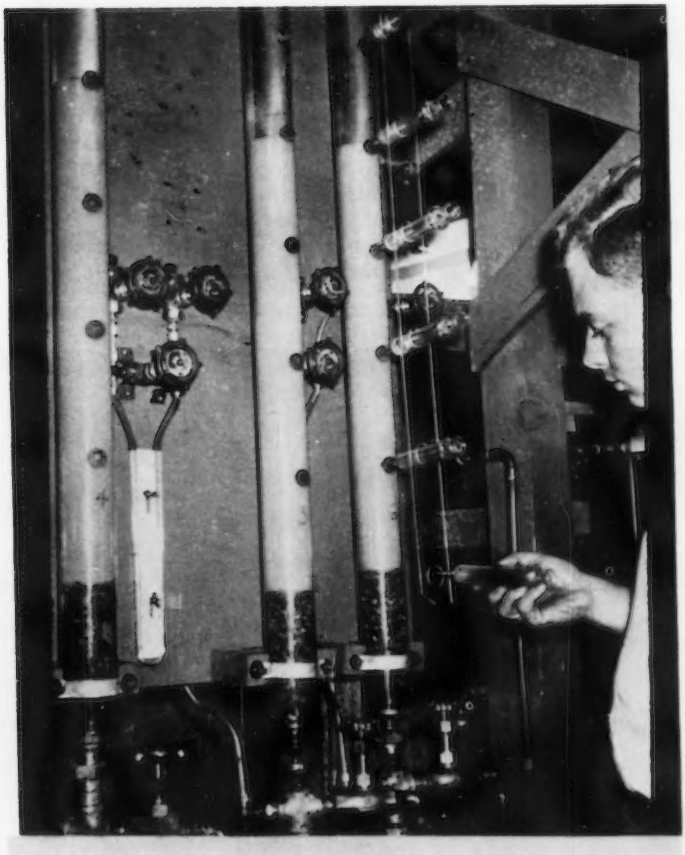
Backwashing is done with partially deaerated Cincinnati tap water. No surface wash is used in these small columns.

All effluents and wash water go into a large stainless steel sump where they can be monitored and decontaminated before they are discharged to the sewer.



FRONT VIEW OF SIX 2-INCH SAND FILTERS

FIGURE 4



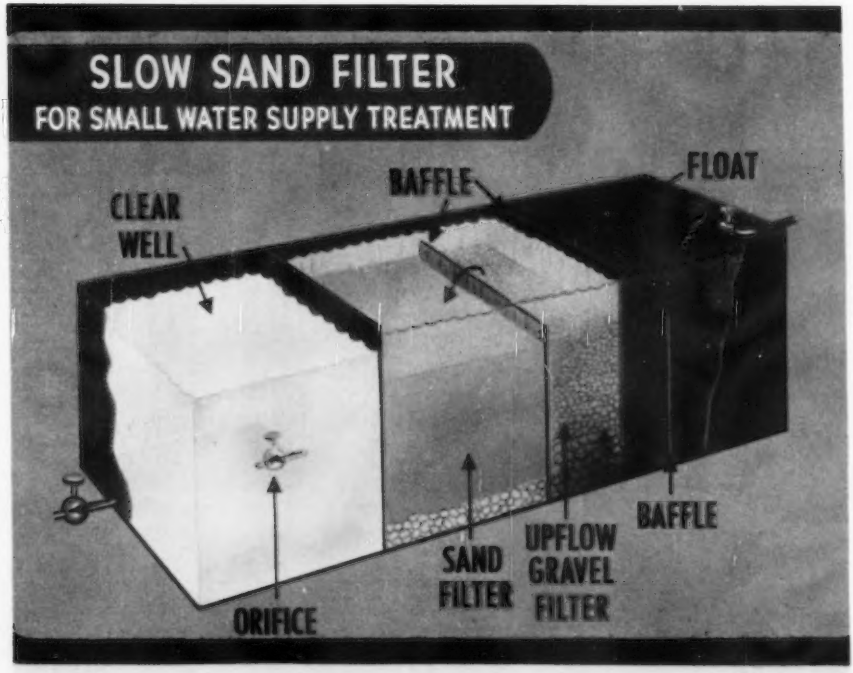
SAMPLING WATER FROM SAND FILTERS WITH SYRINGE AND NEEDLE THROUGH SELF-SEALING RUBBER PORTS

FIGURE 5

Small Water Supply Plant

This 0.3-gpm plant is designed to settle and filter river or farm pond water in preparation for disinfection. Application to the filters is at the typical slow sand-filter rate of 50 gpd/sq. ft. In the case of turbid river water, the coarse particles are first removed in a 100-gallon settling tank, after which the flow is directed up through a 5-sq. ft. fine gravel bed 2 feet deep, and down through a 10-sq. ft. fine sand bed, also 2 feet deep. (See Figure 6).

The water is then chlorinated or heated to 161° F for 15 seconds to make it bacteriologically safe. The present arrangement uses an electric heater in conjunction with a heat exchanger to kill economically the pathogenic organisms that still may be present. Thus, it is similar to pasteurization of milk, and much easier to operate and maintain than a chlorinator. Finished water is then stored in a 400-gallon tank so that peak daytime demand can be adequately handled. Average daily demand for a family of five is estimated to be 250 gallons.



CROSS-SECTIONAL VIEW OF SLOW SAND FILTER FOR SMALL WATER SUPPLY TREATMENT

FIGURE 6

Instrumentation

A few unique instruments are being used in conjunction with the plant and may be of interest to designers as well as researchers.

In determining the loading and the efficiency of any treatment unit, it is convenient to know the number and size of particles or organisms in the water. A recently acquired apparatus called a Coulter Counter will do this over a particle-size range of about 0.6 microns to 200 microns. A suspension of particles in an electrically conductive liquid is forced through a small orifice or aperture, flanked on each side by an immersed electrode. As each particle passes through the aperture, it replaces its own volume of electrolyte within the aperture, momentarily changing the resistance value between the electrodes. This change produces a brief voltage pulse having a magnitude proportionate to particle volume, and the resultant series of pulses is electronically amplified, scaled, and counted. Although the Counter costs about $4,000, it speeds up much of the work and gives information on particle-size distributions that are not otherwise readily available.

A microphotographic apparatus using a Polaroid-Land camera provides an opportunity to make a rapid study of everything from sand- to floc-particles.

A single-channel pulse analyzer allows for the use of gamma emitting radioactive tracers in a variety of ways.

To make time-lapse observations of meters, filters, flow patterns, etc. an 8-mm movie camera has been modified to take single-frame pictures at almost any desired time interval over an extended period.

An automatic sampling device, normally used in chromagraphic work, has been set up to collect two hundred, 25-ml portions of the effluent at any desired interval from 0.5 to 30 minutes.

The usual laboratory instruments are also available either in the pilot plant area or in a special analytical service room.

Present and Proposed Studies

Filtration Studies

The six, 2-inch diameter filter columns are being used in the first studies to help define the role of sand and other media in removing particulates. The initial effort has been confined to working with clean sand of a selected uniform size and applying water to the bed with a known quantity of particles at a given rate. Thus it will be possible to determine the influence of sand size or shape, bed porosity and depth, and flow rate on the removal of various-sized particulates. Bacillus globigii, a bacterial spore approximately 1 micron in size, is one of the test contaminants. Talc in the 1- to 10-micron range is being used to provide a contaminant with a specific gravity of ~ 2.6. Other particles such as amebic cysts, bacteria, pinpoint floc, plankton, clay, and pulverized metals will also be used in the near future.

The tests on the influence of sand size and bed depth have not progressed far enough to make any conclusions, but it may be of interest to mention some of the operational problems that have been overcome during the last several months.

When using spores, duplication was difficult since even heavy prerun chlorination and complete coverage of the system did not always suffice in suppressing vegetative bacteria throughout a 36-hour period. Heat shocking

the samples at 80° C for ten minutes before plating managed to kill interfering organisms and leave the spores unaffected.

The entrainment of air in the filter bed was reduced by storing all makeup and backwash water for at least 24-hours at room temperature, and by partially deaerating the backwash water.

Mixing of gravel with sand was stopped by supporting the sand bed on fine stainless steel screen. This also served to minimize sand leakage.

The purity and clarity of the makeup water was increased by demineralizing it and putting it through a small pressure filter.

Duplicate loading of parallel filters was accomplished by reducing the concentration of particles and the volume of reservoirs ahead of the columns. The particle counter previously described was used to determine small turbidity loading and removal.

A steady low or high rate of flow was finally achieved by using expensive but precise gear pumps on the effluent end of the filters.

Rust formation in the system was reduced by using all stainless steel or plastic material, and by keeping the pH elevated to at least 8.

Sampling within the sand bed was accomplished by using a 20-ml syringe and 3/4", #23 needle to withdraw a portion very slowly through a self-sealing rubber stopper. This only typifies some of the problems encountered in small-scale pilot-plant operation.

Later this small plant will be used to study the influence of speed and time on the mixing of coagulants; the quantity of work to produce a floc of certain strength; the characterizing of good floc and the degree of and reasons for floc penetration and its relationship to bacterial, viral, or algal penetration.

Large Pilot Plant Studies

Thus far, no major projects have been started with the large pilot plant. Time was required to work out the hydraulics, sampling devices, and metering to ascertain if the two parallel plants work with equal success. Raw water intake problems have slowed up operations considerably.

Fluorescein dye tests are being made to determine flow-through times and current patterns, particularly at inlets and outlets. Many of the design factors studied in the small plant will be further checked in this large-scale unit, for example, flow rate, sand size, and bed depth.

The plant will be more suited for testing overflow rates in settling tanks; checking surface and backwashing techniques with various filter media, wash water troughs and underdrains; determining relationship between head loss, floc strength, and penetration of organisms; feeding and mixing of coagulants; and filtering through a bed made of two types of media. Modifications will permit operation without rate controllers or with a tapered flow rate. Upflow filters can be arranged also. Much effort will be spent on ways of producing good settleable floc with a minimum of coagulants or aids, such as activated silica or polyelectrolytes. This will be done partly by attempting to get better correlation between jar test results and plant scale results.

These tests indicate future research studies planned for this plant. The plant will also serve to test the reaction of some new contaminants, such as fish poisons, synthetic organics, radionuclides, toxic metals, and biological forms, when they are added to a large flow-through system. It should help to re-evaluate the pollutional loading that each unit process can handle and thus aid in establishing raw water quality limitations.

Small Water Supply Studies

Since many rural and suburban water supplies have been depleted or contaminated, there has been a growing need for an inexpensive and safe process for treating surface or contaminated ground water. Standard municipal treatment practices have proved unrealistic and even many small chlorinators have not proved completely effective at all times.

Based on the experience of milk pasteurization, heat disinfection appears to be the best answer to the problem. However, before a heater can be used efficiently for long periods, the turbidity of farm pond water has to be reduced.

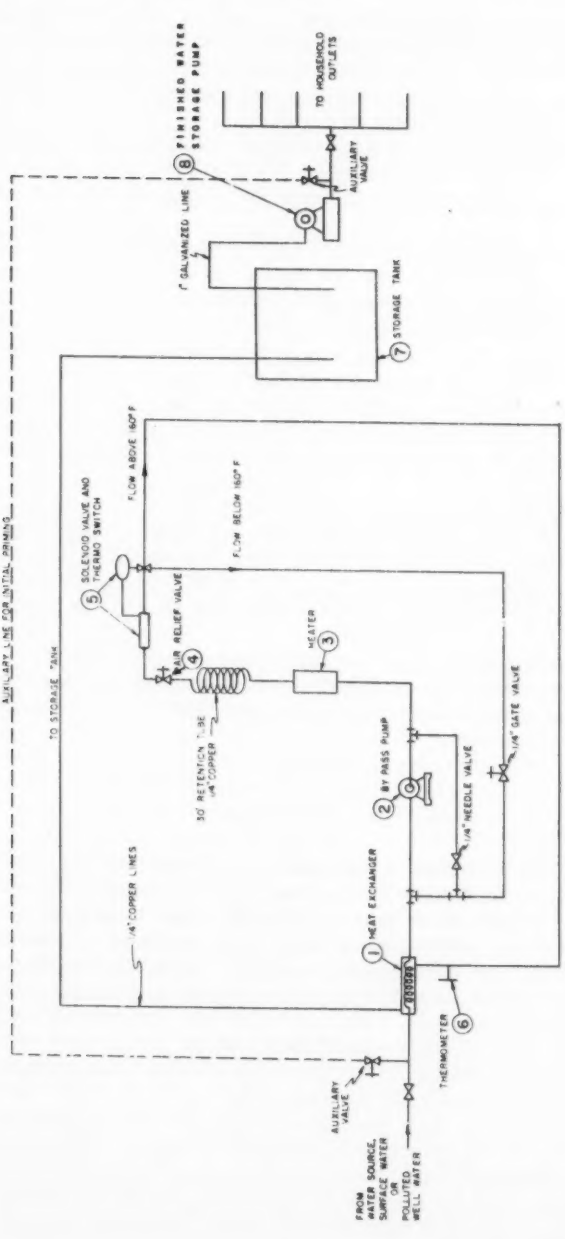
Studies are being conducted at the Center and in the field to determine the best way to clarify and then heat the water. Thus far, a unit with an upflow roughing filter of gravel followed by a conventional slow sand filter does a reasonable job of clarification. Many details of design, media, rates, etc., need further study. For instances, in some cases it may be necessary to incorporate activated carbon in the system to remove earthy or fishy odors.

After several months of testing, it appears that a hot water tank with two, 1500-watt heating elements in an insulating jacket will heat a daily water demand of 250 gallons, provided the heat exchanger is large enough to maintain the necessary temperature rise of incoming water within ten degrees. Thus the heater only boosts the water temperature from 151° F to 161° F. The operating cost of this disinfection process in a flow through plant is about $2./family/month. Material costs will vary between $600. and $700, depending on pump requirements. The total cost, with a 10-year amortization, is about $0.23 per 250 gallons. A report on this work is to be published soon. (See Figure 7).

A field installation on a private farm pond near Cincinnati is in operation and will help to determine the durability of parts, efficiency of heater and heat exchanger, and cost of maintenance and operation over an extended period - perhaps of several years.

SUMMARY

The pilot plant facilities in the Public Health Service's new Robert A. Taft Sanitary Engineering Center in Cincinnati provide an opportunity to study old and develop new methods of water treatment. The three water plants of various sizes now in use allow studies to be made on the basic phenomena of filtration and on the operation of large coagulation and settling tanks, and to determine the most economical preparation of a small supply of safe water from a farm pond.



EQUIPMENT FLOW SHEET
HEAT PASTEURIZATION UNIT

FIG. 7

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

SLUDGE TREATMENT AND DISPOSAL BY THE ZIMMERMAN PROCESS

Twenty-third Progress Report of the Committee on Sanitary Engineering Research of the Sanitary Engineering Division

SYNOPSIS

Treatment and disposal of sewage sludge as practiced today generally is dependent upon anaerobic biological conversion and modification of raw sludge solids preparatory to final disposal. Engineers long have been interested in ways and means of improving on or even circumventing the time consuming and expensive biological phase of sludge treatment. A new wet combustion process for destroying organic sludge was recently reported on. Known as the Zimmermann Process it was studied on a pilot plant scale at the Southwest Works of the Metropolitan Sanitary District of Greater Chicago. Results obtained to date suggest that design engineers could give serious consideration to the use of the Zimmermann Process in treating sewage sludge.

INTRODUCTION

In most sewage treatment plants the sludge handling and treatment facilities represent a substantial capital investment. While functional needs and unit cost factors may vary the sludge disposal phase of sewage treatment generally represents from 20 to 40 per cent or more of the total treatment cost. Much of this cost is tied up in facilities designed to biologically destroy a portion of the raw sludge organic solids. Substantial improvements have been made during recent years in the process of anaerobic sludge digestion. Satisfactory operating experiences with conventional digester loading rates coupled with recent process improvements may have diminished interest in alternative sludge treatment methods.

From a theoretical point of view there are several alternative approaches to sludge disposal. Some of these have been tried with varying degrees of success. Included in this category are heat treatment, chemical conditioning,

Note: Discussion open until December 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2087 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. SA 4, July, 1959.

and combustion or incineration. The Zimmermann Process being reported on in this article is still another approach to the problem of ultimate sludge disposal. It offers a means of oxidizing organic sludge solids in an aqueous phase by means of dissolved oxygen.

In selecting any unit operation, the design engineer must satisfy himself as to its functional performance, reliability and cost. It is not the purpose of this report to compare sludge disposal processes or to discuss process economics, etc. Rather the intent is merely to describe to the profession a new sewage sludge treatment operation based on research and development reports of Sterling Drug, Inc.

The Zimmermann Process

1. Basic Principles of Operation

Theoretically any organic compound can be oxidized in aqueous solution if sufficient energy is supplied to carry out the reaction. Energy can be supplied in the form of pressure and/or heat. This is the basis of the Zimmermann Process. In this process sewage sludge organics are chemically oxidized in an aqueous phase by dissolved oxygen in a specially designed reactor at elevated temperature and pressure. Typical reactor conditions are 500-600°F. and 1,000-2,000 psig.

Temperature

Reactor temperature can be selected anywhere below 705°F.---water's critical temperature above which water can no longer exist in a liquid phase. As expected both oxidizability of sludge solids as well as oxidation reaction rate are markedly influenced by temperature. The significance of reactor temperature is shown in Figs. 1 and 2.

Air Requirements

The fuel value of sewage sludge requires an external supply of oxygen in order to achieve complete oxidation. As in the case of conventional fuel combustion air is employed as the source of oxygen. Since work must be done in supplying air to the process, both thermal efficiency and process economy are a function of air input. Other things being equal, optimum efficiency requires maximum heat production per pound of air supplied. Optimum air requirements are in turn determined by the so-called fuel value of the organic materials being oxidized. Heat values and theoretical air requirements for a number of common fuels and for several waste substances are shown in Table 1.

Air supplied to the process becomes saturated with steam from contact with water in the reactor. Obviously the greater the amount of air supplied per unit amount of liquid sludge, the greater the amount of steam carried out of the reactor, other things being equal. Thus it becomes possible to evaporate all water in the reactor merely by supplying a large enough quantity of air. Since the presence of liquid water in the reactor is essential, there is a limit to the air input rate which can be tolerated. In summary then, the air requirements of the process are determined by three things: (1) the heat value of the sludge being oxidized in Btu./pound of air; (2) the reactor conditions as shown in Fig. 3 and; (3) the moisture content of the sludge.

High Temperatures Give Low Reaction Time and High Oxidation

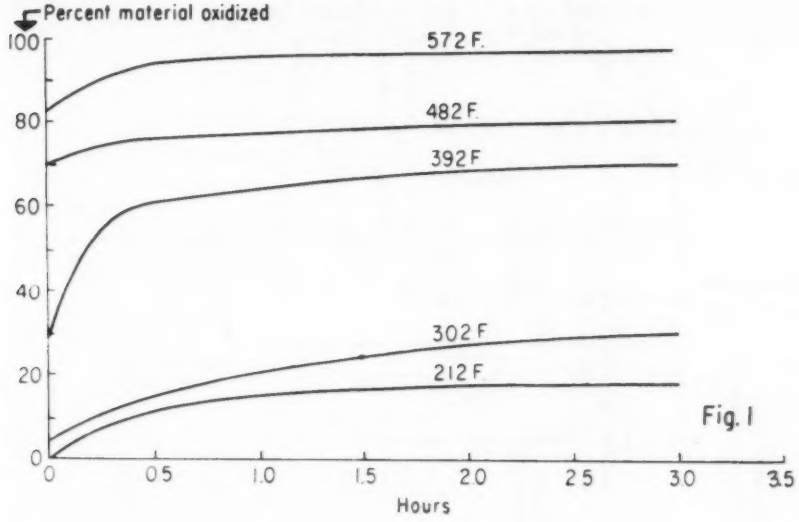


Fig. 1

Amount of C.O.D. Removal is Mainly Function of Reaction Temperature

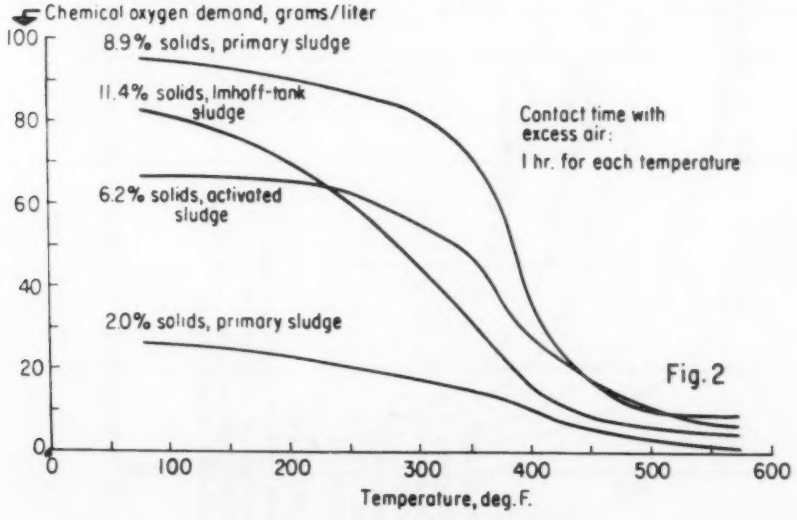


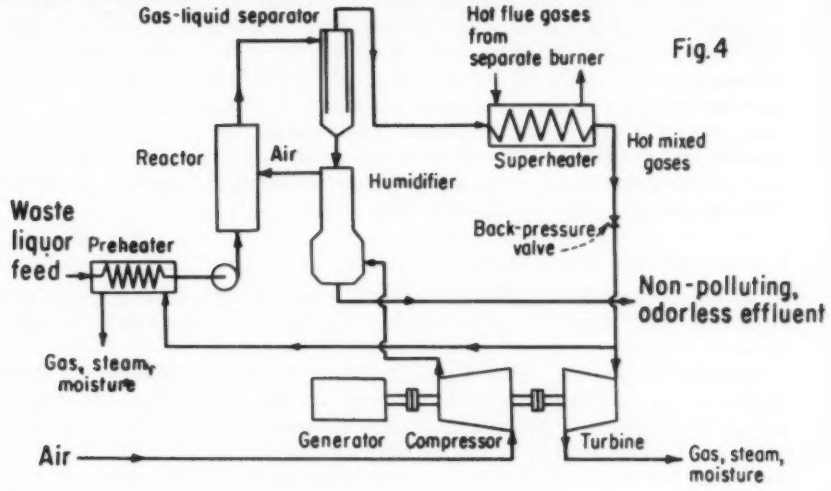
Fig. 2

TABLE 1. Heat Values and Air Requirements for Several Fuels and Some Organic Wastes*

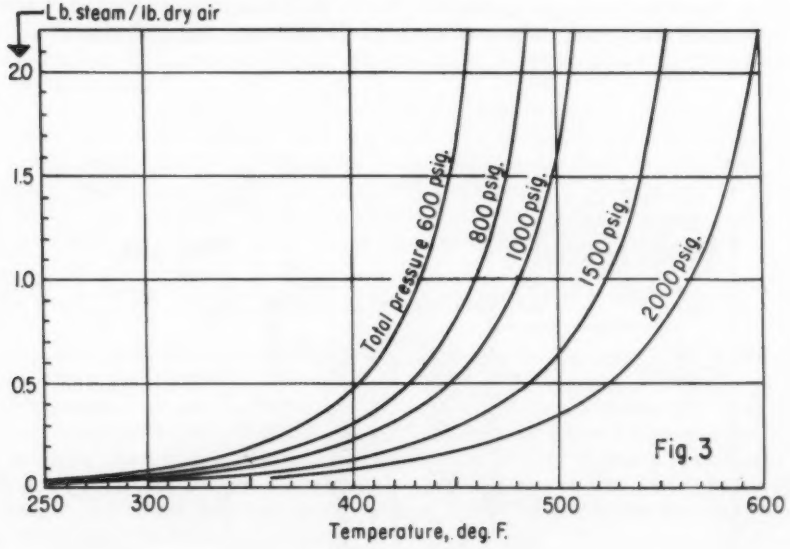
	HEATING VALUE	OXIDANT REQUIRED FOR COMPLETE COMBUSTION		HEATING VALUE
	Btu./Lb. Material	Lb. O_2/Lb. Material	Lb. Air/Lb. Material	Btu./Lb. Air
FUEL MATERIALS:				
Hydrogen	61,000	7.94	34.34	1,780
Ethylene	21,460	3.42	14.8	1,450
Carbon	14,093	2.66	11.53	1,220
Oxalic acid	1,203	0.18	0.77	1,565
Fuel oil	19,376	3.26	14.0	1,380
Lactose	7,100	1.13	4.87	1,455
WASTE MATERIALS:				
Waste sulfite liquor solids	7,900	1.32	5.70	1.385
Semichemical pulp solids	5,812	0.96	4.13	1,410
Primary sewage sludge	7,820	1.33	5.75	1,365
Activated sewage sludge	6,540	1.19	5.14	1,270

*Source: Zimmermann, F. J., Chemical Engineering, pp 117-120, August 25, 1958.

Flow Diagram for Wet Waste Air-Oxidation Process



Steam-Air Ratio Determines Reactor Conditions



Pressure

In order to carry out the oxidation in an aqueous phase sufficient pressures must be maintained in the reactor to cause condensation of water vapor as temperatures are increased above 212°F. The amount of water vapor carried out of the process by reactor gases can be controlled by varying temperature and pressure as shown in Fig. 3. The importance of operating pressure becomes more apparent when examined in terms of process air supply rate. An air supply rate of 4 pounds/gallon of sludge would be adequate to cause complete evaporation of the aqueous reactor phase for sludges containing 8 or less pounds of water per gallon when reactor pressure conditions allow a steam-air ratio of 2 pounds (see Fig. 3).

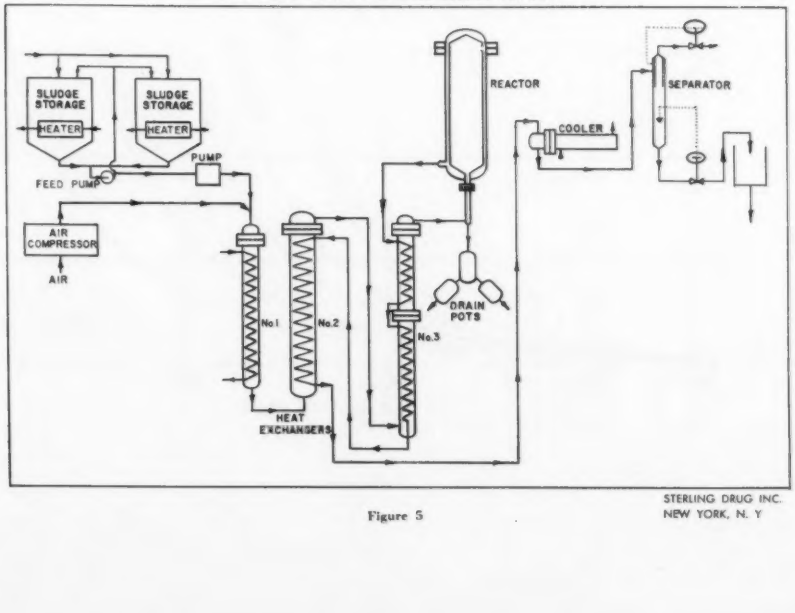
2. Process Flow Diagram

A generalized flow diagram is shown in Fig. 4. The flow diagram of the pilot-plant unit employed in the recent Southwest Works study at Chicago is shown in Fig. 5.

Briefly the process steps are as follows. Sludge or waste liquor is preheated in one or more heat exchangers by hot exit reactor gases, steam, and water. The sludge is pressurized prior to passage through the heat exchangers. Air is combined with preheated slude and the mixture introduced at the bottom of the reactor. Oxidation takes place as the sludge-air mixture passes upward through a coarsely baffled path. Reactor effluent is cooled in passage through the preheaters. Following cooling by-product gases and liquor are separated prior to final disposal.

As indicated by the flow diagrams, several innovations and variations in process operation are possible. These modifications are aimed at improving thermal efficiency. Obviously if a waste material has sufficient fuel value

ZIMMERMANN OXIDATION PLANT
FOR TWO TONS OF SEWAGE SLUDGE PER DAY



STERLING DRUG INC.
NEW YORK, N. Y

Figure 5

the process can be made to be self-sustaining. While it is theoretically possible to produce excess power during such a waste treatment operation, economic considerations will determine the feasibility of such a practice. Nevertheless sufficient thermal energy may be taken from the reactor in the form of hot gases and steam to drive turbines adequate to provide air compression and sludge pumping power requirements.

Pilot Plant Study

A pilot plant scale evaluation of the Zimmermann Process as a means of treating sewage sludge was undertaken. It was planned that comprehensive studies would be made employing primary sludge, activated sludge and various combinations of the two. Sludge storage and sludge thickening facilities were included to allow variation of sludge solids concentration. The pilot plant (Fig. 5) was completed and ready for operation on September 13, 1957. The first sludge was treated on September 24.

The pilot plant has a rated capacity of about 2 Tons of sludge per day (dry basis). The process was operated at a pressure of 1,200 p.s.i.g. and a reactor temperature of about 500°F. Auxilary power recovery facilities were not installed since the power required to operate the entire pilot plant was only 80 H.P. Theoretically the process would be self-sustaining with a sewage sludge of about 3 per cent or more solids.

1. Experimental Results

Operational data obtained during the period September 24, 1957 to March 28, 1958 are presented in Tables 2, 3, and 4. These data indicate that volatile matter reduction is independent of sludge solids concentration. This was to be expected since, as shown in Fig. 2, the oxidizable fraction is a function of reactor temperature.

The process effluent was found to be relatively high in ammonia, volatile acids, and BOD content. Process effluent quality appears to be influenced by sludge composition. Just as in the case of conventional digester supernatant Zimmermann Process effluent apparently will require some form of treatment prior to final disposal. In most cases such treatment would most readily be provided by existing primary and secondary treatment plant elements.

SUMMARY AND CONCLUSIONS

The Zimmermann Process represents a promising new approach to sludge treatment. The basic principles upon which the process is based are well known fundamental concepts of physical chemistry and thermodynamics. Apparently as much as 90 per cent of the organic matter contained in domestic sewage sludges can be oxidized by dissolved oxygen at 500°F. and a pressure of 1,200 p.s.i.g. When the concentration of volatile sludge solids becomes great enough, sufficient thermal energy can be recovered from the wet combustion to operate the entire process.

Functional performance of the Zimmermann Process has been amply demonstrated with pulp mill wastes and with domestic sewage sludges. A $4 million wet combustion plant reportedly is being built for the Borregaard Paper Co. in Norway. At the present time sufficient data and information are

Table 2. RECORD OF RUNS MADE BY ZIMMERMANN PROCESS

CHICAGO SANITARY DISTRICT
Sept. 24, 1957--March 28, 1958

Run No.	Duration Hrs.	Sludge Processed Gal.	Type of Sludge	Total Solids %	Volatile Matter %	Air Used Lbs./gal.	Heating Value Btu/gal.	Reactor Temp. °F.	Solid Organic Matter Removed %	Ash in Insolubles After Oxidation %
1	14	3150	A	---	---	---	---	470	---	---
2	24	5875	A	---	---	1.2	---	505	---	---
3	8	2830	A	3.1	2.0	1.1	1805	497	90.0	85.3
4	24	5470	50%P-50%A	4.2	2.9	2.1	3190	513	94.5	89.4
5	45	10235	50%P-50%A	3.5	2.3	1.3	2145	498	92.1	87.7
6	64	12375	P	4.8	3.5	2.2	3290	519	96.0	90.3
7	46	9625	A	3.6	2.2	1.2	1785	487	92.0	88.4
8	141	33270	60%P-40%A	4.7	3.2	2.2	3140	515	91.8	84.1
9	131	26580	P	6.0	4.2	2.4	3940	518	95.6	90.4
10	366	78115	50%P-50%A	4.9	3.4	2.0	3078	500	93.1	86.0
11	42	9630	50%P-50%A	6.6	4.8	2.6	3945	521	94.1	86.3
12	84	19960	50%P-50%A	7.0	5.0	3.0	4490	519	93.9	86.8

A = Activated Sludge

P = Primary Sludge

P = Primary Sludge

TABLE 3. Reduction of Total Solids, Volatile Solids, COD

The Zimmermann Process - Southwest Sewage Treatment Works

Solids Concentration Range Per Cent	AVERAGE OF EACH RANGE												pH Range
				Influent			Effluent			Reduction			
	Thruput gph	Pressure psi	Temp °F	Tot.Sol. per ct.	Vol.Sol. per ct.	COD gm/ liter	Tot.Sol. per ct.	Vol.Sol. per ct.	COD gm/ liter	Tot.Sol. per ct.	Vol.Sol. per ct.	COD per ct.	
3.00-3.99	219	1220	490	3.58	2.40	45.8	1.08	0.30	10.1	70.1	87.4	78.0	6.4-7.6
4.00-4.99	244	1208	508	4.43	2.93	56.9	1.48	0.35	11.5	65.6	87.1	79.9	6.8-7.8
5.00-5.99	221	1209	510	5.23	3.49	63.6	1.76	0.40	13.9	65.7	87.6	78.1	7.1-7.6
6.00-6.99	245	1215	518	6.27	4.53	81.7	1.40	0.34	16.8	77.6	92.4	79.4	7.7-7.9
7.45*	253	1202	507	7.45	4.08	66.2	3.81	0.60	12.7	48.8	85.4	80.8	

* Centrifuge activated sludge. Per cent ash, 45.3

Source: Unpublished report by E. Hurwitz, "The Zimmermann Process - Results Obtained at the Southwest Treatment Works of the Metropolitan Sanitary District of Greater Chicago," October 3, 1958

TABLE 4. Chemical Characteristics of Reactor Effluent

The Zimmermann Process - Southwest Sewage Treatment Works

Solids Concentration Range Per Cent	AVERAGE OF EFFLUENT					AVERAGE OF SETTLED EFFLUENT		AVERAGE OF EFFLUENT	
	Reactor Effluent								
	NH_3-N mg/liter	Org.N mg/liter	Vol.Acids as acetic mg/liter	BOD mg/liter	COD mg/liter	BOD mg/liter	COD mg/liter	Volume settled in 1 hour ml/liter	Ash COD left in ash mg
3.00-3.99	1220	313	----	4990	10100	4010	8400	---	----
4.00-4.99	1400	442	2960	5760	11500	5280	8300	100	3200
5.00-5.99	1650	482	4090	7600	13900	6590	10500	116	3400
6.00-6.99	1780	535	3960	8570	16800	6870	11500	116	5300
7.45*	1910	554	2790	5880	12700	5580	9300	139	3400

* Centrifuged activated sludge - Per cent ash, 45.3

Source: (See preceeding table footnote)

not available to allow detailed design or economic analyses of the process by consulting engineers. Based on results of the Chicago pilot plant study, construction costs would range from about $50,000 per Ton per day (dry basis) rated capacity for small plants having a capacity of about 5 Tons per day to about $25,000 per Ton per day for plants for 100 Tons per day capacity. Operating costs are even more difficult to assess. However, according to figures released by Sterling Drug, Inc., operating costs might be expected to range from about $6.30 to $14.80 per ton (dry basis) of sludge solids processed.

Credit

This research report, one of a series of professional contributions by the Committee on Sanitary Engineering Research,

	William T. Ingram	Air Pollution
	E. R. Hendrickson	
	Ralph Stone	Refuse
	R. H. Bogan	Sewage
	C. H. Hull	Water
	M. A. Churchill	Stream Pollution
	H. A. Faber	Public Health
Chairman,	N. L. Nemerow	Industrial Wastes

has been prepared by the Sewage Treatment Section.

R. H. Bogan, Head

ACKNOWLEDGMENT

The Sanitary Engineering Division gratefully recognizes the professional courtesy and generosity of Sterling Drug, Inc. and particularly Messrs. James Hill, Jr., and F. J. Zimmermann in making research reports and data available to the Society for review, presentation and comment by the Sewage Treatment Section of the Research Committee.

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

DUST PROPERTIES AND DUST COLLECTION[a]

B. Gutterman,[1] A. M. ASCE and W. E. Ranz[2]

SUMMARY

Analytical methods have been developed which permit calculation of re-entrainment and backmixing characteristics of dust suspensions and dust layers. The methods are based on the physical properties of the dust and the fluid conveying or acting on the dust.

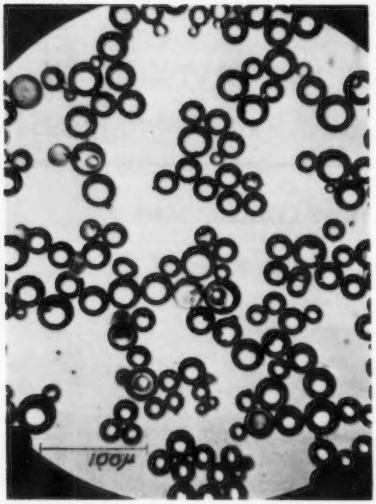
INTRODUCTION

This research was a basic study of some of the physical properties of dust suspensions and dust layers and the relation of these properties to dust collection. If the behavior of dust suspensions and dust layers in a collector were known in some detail, if simple test procedures were available for predicting this behavior, costly trial and error designs, long developments, and faulty applications of dust collectors might be avoided. It was the intent of this investigation to establish the relationship between the physical properties of dust and critical pickup or entrainment velocity. Further, an attempt was made to elucidate the mechanism or mechanisms responsible for backmixing of dusts, that is, to establish the relation between physical properties of dust and the distribution of dust concentration in a turbulent gas flow along a collecting surface.

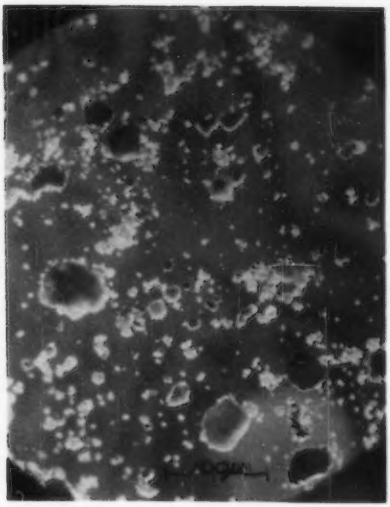
Note: Discussion open until December 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2088 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. SA 4, July, 1959.

a. This investigation is part of research under Research Grant S-19(c) undertaken at the Pennsylvania State University under the sponsorship of the U.S.P.H.S. The work was also supported (in part) by a traineeship (AT57-201) from the Public Health Service.

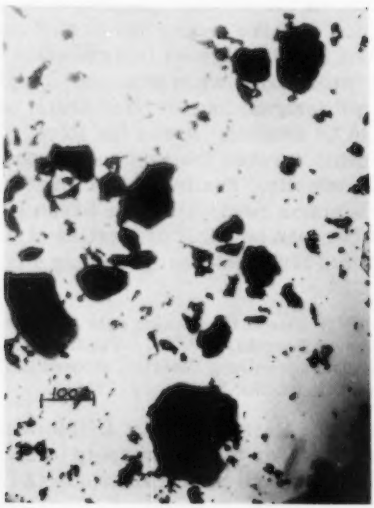
1. Presently, Environmental Health Training Specialist, Commonwealth of Pennsylvania, Dept. of Health, Harrisburg, Pa., formerly with Pennsylvania State Univ., University Park, Pa.
2. Prof. of Chem. Eng., Univ. of Minnesota, Minneapolis, Minn.



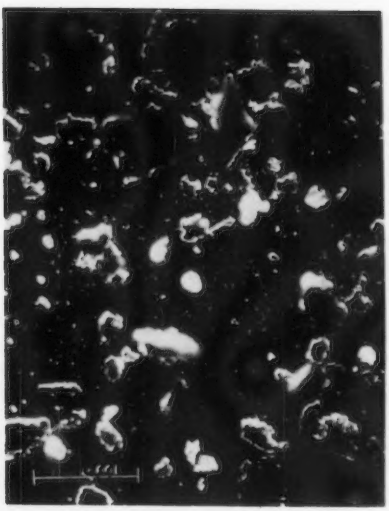
Glass Beads



U. C. Fly Ash



Iron Dust



Cork Dust

Fig. 1

Physical properties such as internal friction, surface friction, particle density and particle size, and cohesion were analyzed. Particle shape was specifically omitted because of its extreme variability. The shape factor, however, is not overlooked, but incorporated into such parameters as surface and internal friction.

Materials tested were sand, glass, tin, cork, corborundum, and fly ash. Photomicrographs of some of these dusts appear in Fig. 1. Order of magnitude values rather than precise quantities were obtained in order to get the broadest, most significant information from so general a study.

Physical Tests of Dusts

The physical tests on the dusts used in this study were divided into two parts. The first part consisted of normal tests such as particle size, particle size distribution and specific gravity. The second part consisted of special tests which were adapted or devised for this research. These special tests were internal friction, surface friction, and cohesion.

TABLE I

SUMMARY OF PHYSICAL PROPERTIES

Material	Size Range (Microns)	Average Particle Size (Microns)	Specific Gravity	Internal Friction Angle Ψ	External Friction Angle coeff of friction with Aluminum f°	Cohesion grams/in^2
Union Carbide	420-590	505	1.95	.468	.300	13.5
Fly Ash	295-420	358	1.97	.467	.404	0.5
	250-295	372	1.99	.369	.354	5.4
	149-250	200	2.01	.449	.539	20.5
	105-149	127	2.10	.292	.441	13.5
	74-105	89.5	2.19	.400	.515	0.5
	44-74	59	2.29	.338	.297	14.5
	0-44	22	2.36		.256	14.5
Cottrell	149-250	200	2.18	.326	.230	8.5
Fly Ash	105-149	127	2.13	.436	.374	
	74-105	89.5	2.53	.252	.259	5.0
	44-74	59	2.69	.163	.212	6.0
	0-44	22	2.69	.0275	.272	21.0
Tin	149-250	200	7.02	.845	.480	31.0
	105-149	127	7.33	.623	.432	1.0
	74-105	89.5	7.33	.505	.472	33.0
	44-74	59	7.33	.589	.398	24.0
	0-44	22	7.25	.137	.405	31.0
Iron	149-250	200	7.42	.344	.338	29.5
	105-149	127	7.97	.347	.258	25.5
	74-105	89.5	8.03	.399	.342	19.0
	44-74	59	7.59	.367	.334	22.0
	0-44	22	7.33	.424	.326	10.5
#800 Carborundum	----	17	3.165	.263	.284	9.0
#400 Carborundum	----	37	3.17	.330	.371	5.0
Glass Beads	----	25.4	2.50	.246	.192	5.5
Cork	149-250	200	0.24	.307	.232	28.5
	105-149	127	0.24	.452	.306	12.0
	0-105	52	0.24	.401	.282	8.3

In part one, size and size distribution were measured by sieving and microscopic particle count. Specific gravity tests were conducted according to A.S.T.M. Designation D-854. A summary of these properties appears on Table I.

In part two, the internal friction factor, ψ, and cohesion were measured with a specially constructed apparatus similar to the direct shear test used in soil testing. (1) This consisted of a milled aluminum block with a plastic slide (see Fig. 2). A circular aluminum weight of fifty grams was used as the surcharge and additional weight was added to the normal force when needed.

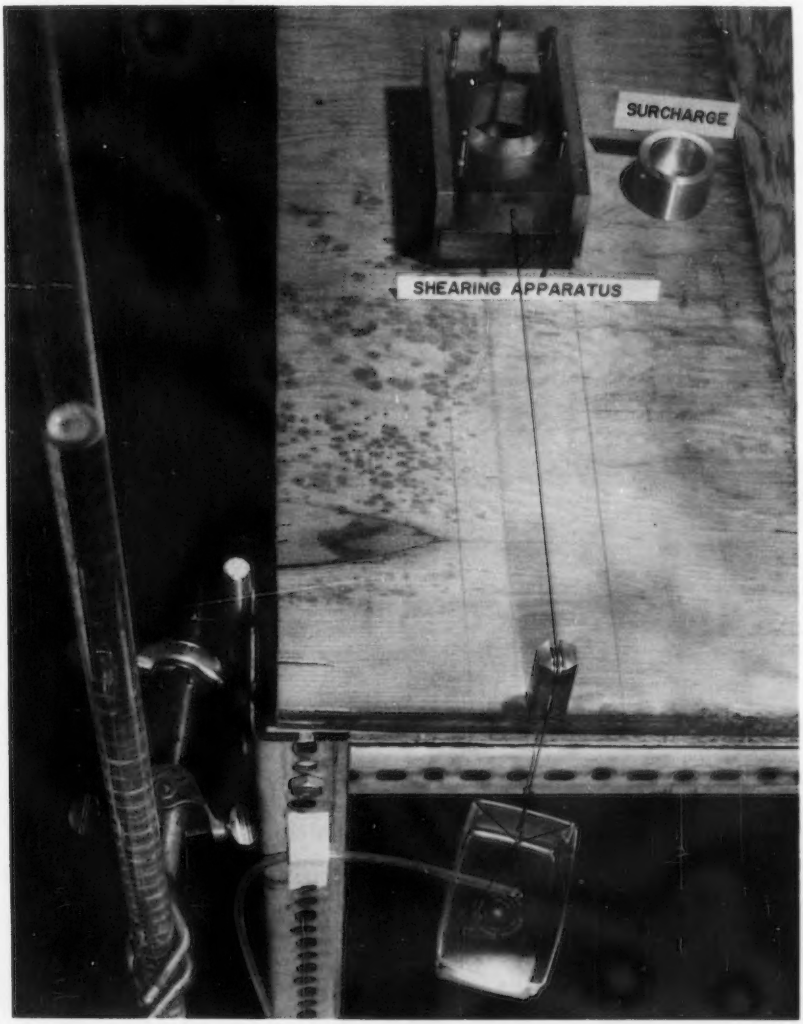


Fig. 2

The particle sample was placed in the shear box by means of a funnel and sharply rapped three times to obtain a standard degree of densification. The lock was released and weight was added to the container, which, by means of a pulley, exerted a horizontal force on the plastic slide. The weight added to the container was increased uniformly and slowly until the specimen failed. With the addition of new material, the normal force was increased and the test repeated. After completing three tests, the results were plotted as shear stress versus normal force. If the points formed a straight line the test was accepted. If not, the tests were repeated until a straight line was obtained.

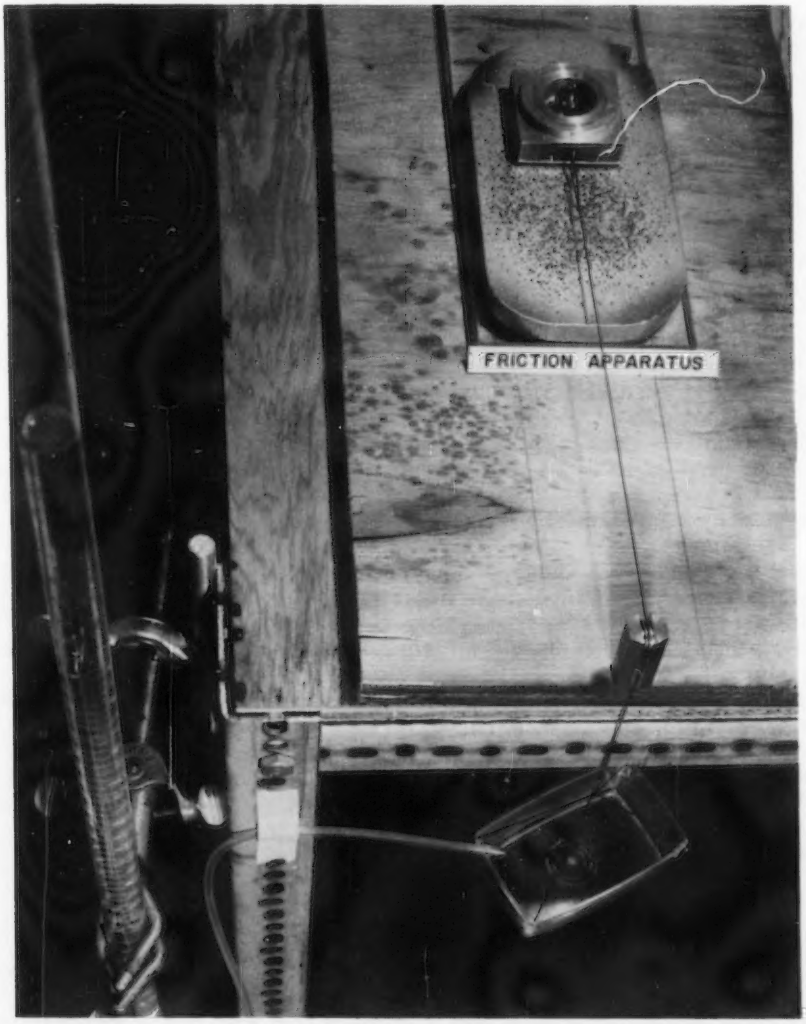


Fig. 3

By extrapolating the line to the point of zero normal force, the value of cohesion was found while the tangent of the angle formed by the straight line gave the angle of internal friction, Ψ. Values of Ψ are found in Table I.

The external friction factor, f*, was obtained by pulling an aluminum block across a mono-particle layer of dust resting on a smooth aluminum plate (see Fig. 3). Once again force was applied by means of adding water to a container until the block began to slide. This method of determining a friction factor gives a combination of sliding and rolling friction and particularly resembles observed conditions in a wind tunnel whose particulate matter is picked up or moved by onrushing fluid.

Apparatus

Figs. 4 and 5 show the test apparatus and schematic diagram of the sampling system. The test equipment consisted of a recirculatory type wind tunnel with a horizontal aluminum test section two inches by five inches by sixteen feet. The air fan was belt driven and had an adjustable butterfly valve mounted directly above the discharge. Mounted on top of the channel, at five foot intervals, were plastic windows which served as observation and sampling ports. Fully developed turbulence was induced by means of saw tooth spoilers placed in the entrance section of the tunnel.

The sampling system comprised a wet test meter, rotameter, vacuum pump, and appropriate pressure sensing devices (one-half and one inch inclined water manometers) which were used in conjunction with miniature impact tubes for measuring velocities in the system. This same system was also used for measuring concentration gradients when the sampling filter was connected to the vacuum line. Various probes were used according to their specific need (see Fig. 6). Probe number one was used for measuring velocity of dust laden streams, number two for sampling, and number three was used for velocity measurements.

The sampling probes, just described, had a diameter approximately 100 times the size of the largest particle tested. These probes were connected under vacuum to the sample holder (see Figs. 7 and 8). The sample holder, different from the thimble type in current use, was made to use glass fiber filter paper. The glass fiber filter paper was chosen because it absorbed no moisture.

To insure constant conditions, that is, no variance of dust properties and gas stream properties due to temperature and humidity, an air conditioner and dehumidifier were installed in the laboratory. By means of the thermostatic control devices on the conditioner, the ambient temperature was kept at 75° F, plus or minus three degrees, and the relative humidity was held at 30 per cent, plus or minus one per cent. All tests were conducted under these conditions.

Procedure for Re-Entrainment Studies

The velocity of air required to move a particle at rest on a surface is defined as the pickup velocity. Experiments concerning re-entrainment were carried out in two parts: 1) pickup from the bottom wall, and 2) pickup from a particle bed.

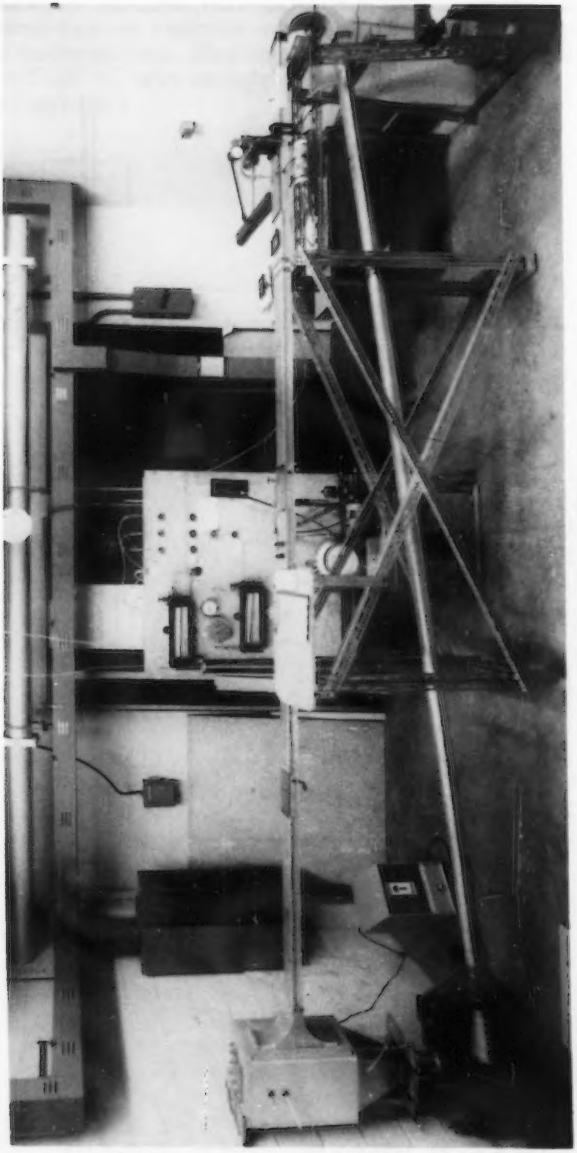


Fig. 4

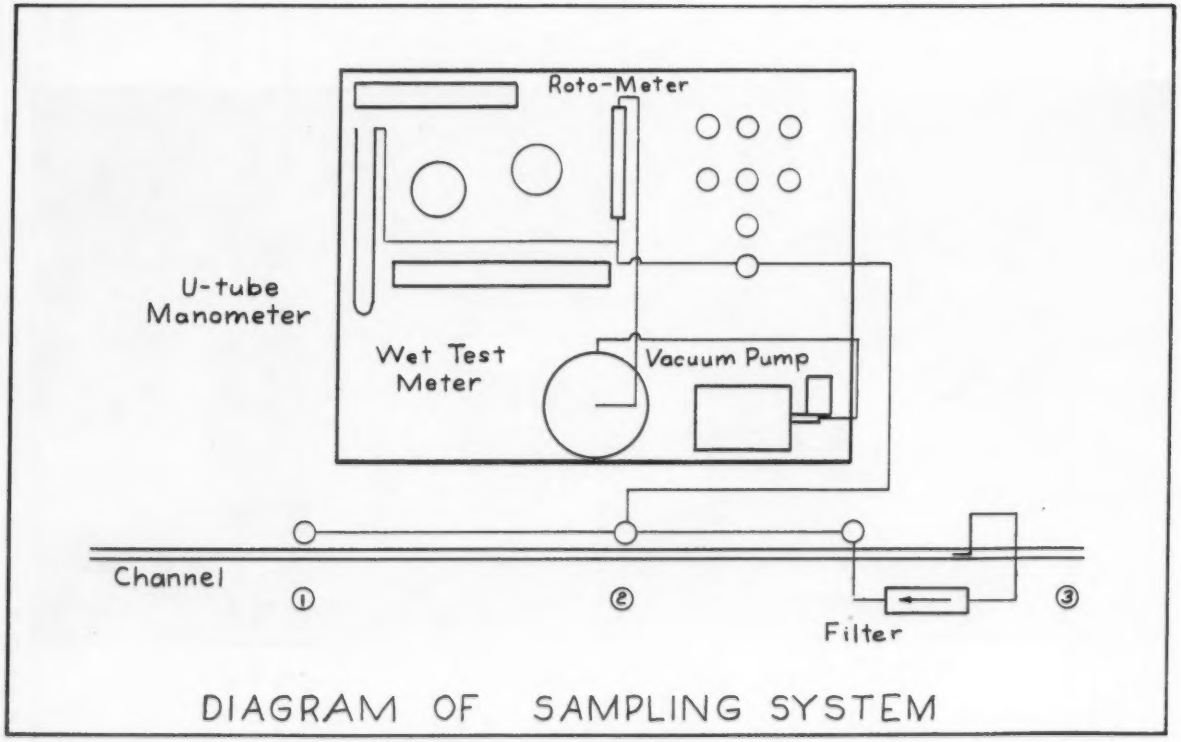
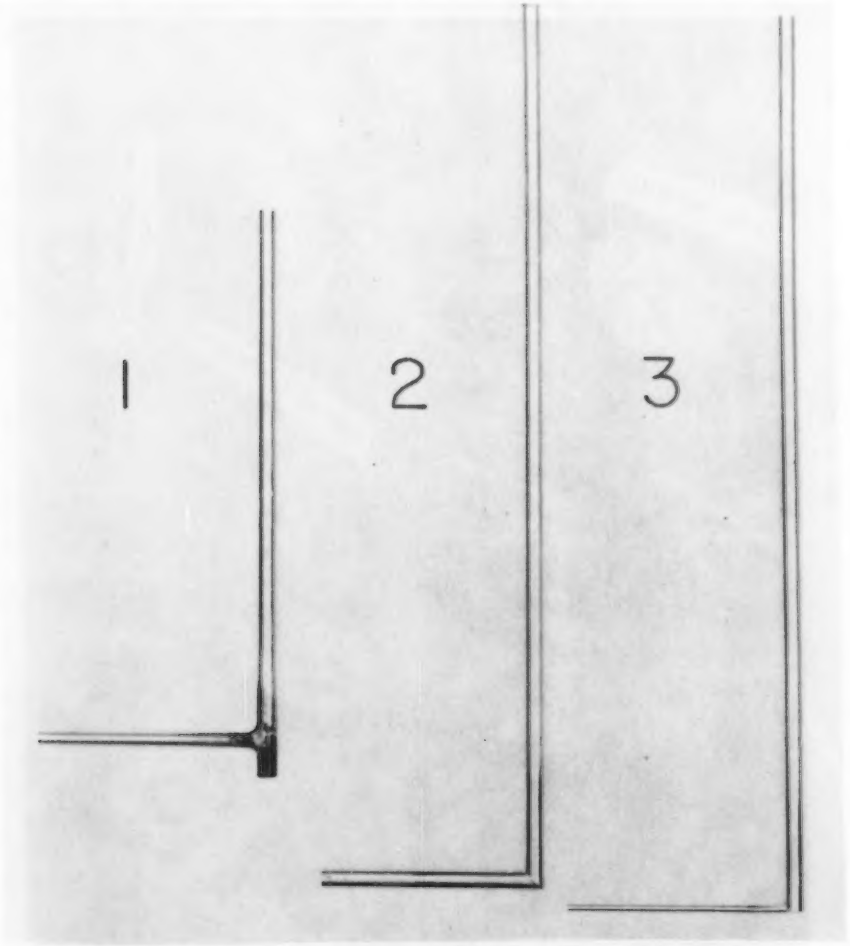


Fig. 5

In t
and ea
spread
micro
the se
locity
throug
summ
rollin

In the first phase, graded dusts were separated into several size ranges and each range represented one test specimen. A specimen was uniformly spread on the floor of the test section and observed by means of a telescopic microscope mounted above the transparent channel top. The air velocity in the section was increased from zero until the particles began to move. Velocity measurements were recorded when particle movement occurred throughout the entire section. Data on pickup from the bottom wall are summarized in Table II. Interestingly, initial movement was noted by a slight rolling and sliding action.



PITOT AND SAMPLE TUBES

Fig. 6

Fig. 5

SA 4

Pickup from the particle bed was accomplished by inserting a grooved aluminum plate and attaching it to the floor of the test section (see Fig. 9). The groove was filled with particles and the top of the particles was leveled with the plate surface. This time, the particles had to roll or slide over the other particles in order to move and wholesale movement occurred only when an upstream particle was lifted into the stream and then impinged upon the bed surface. This bombardment caused one or two or more particles to fly out of the bed and restrike the surface releasing more particles. This action was noted by a series of craters which seemed to be blasted in the particle surface. Bombardment was proved by introducing a dissimilar material

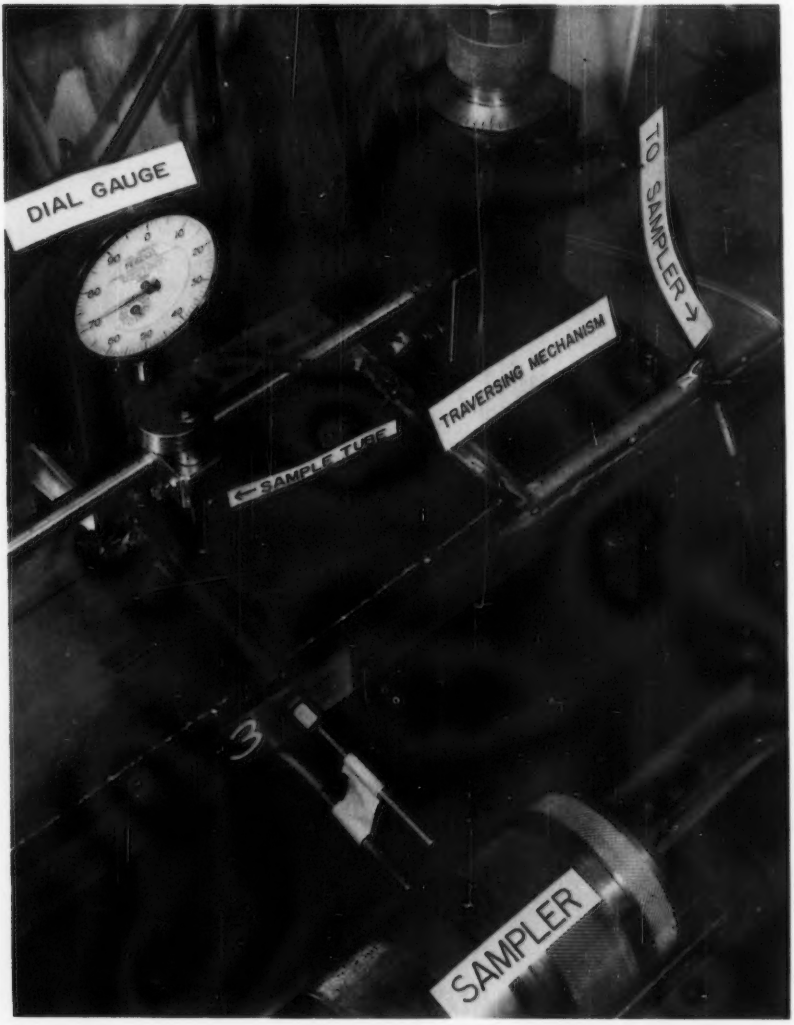


Fig. 7

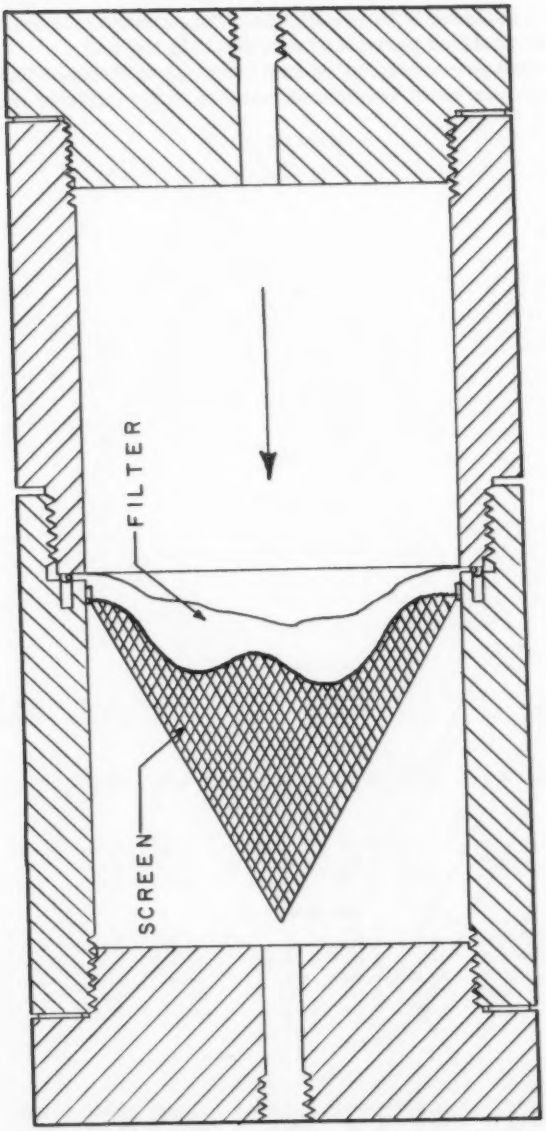


Fig. 8. Sample Holder

upstream and observing the bed. When the craters were produced, a foreign particle was lodged in each hole.

When pickup tests were made, the return line of the re-circulation system was removed and replaced with bag filters. This change was necessary in order to keep recirculated particles from striking the bed.

The observations previously noted are identical to those of Bagnold[2] and confirm his conclusion about conditions necessary for particle movement.

TABLE II

U.C. Fly Ash

Ave D_p (Microns)	D_p(ft) x 10^4	Sg	ρ_p	f*	$D_p^3 \rho_p f^*$ x 10^{12}	$C_D N_{Re}^2$	N_{Re}	T_o (calc) x 10^4	T_o (obs) x 10^4
22	0.72	2.36	4.55	0.256	0.435	0.28	0.0117	2.98	14.0
59	1.935	2.29	4.21	0.297	9.45	6.1	0.252	8.96	8.3
89.5	2.93	2.19	4.22	0.515	54.6	35.3	1.28	19.75	4.57
127	4.16	2.1	4.05	0.441	128.5	83	2.8	20.65	4.57
200	6.56	2.01	3.87	0.539	587.	379	9.5	30.4	4.29
272	8.93	1.99	3.94	0.354	991.	640	14.4	23.9	4.29
357.5	11.7	1.97	3.80	0.404	2710.	1750.	29.6	29.5	5.15
480	15.7	1.95	3.76	0.300	4330	2800	40.8	22.1	4.28
Total Mix				0.494					
				Cottrell Fly Ash					
22	0.721	2.69	5.22	0.272	0.530	0.35	0.0147	3.79	8.29
59	1.935	2.69	5.22	0.212	7.98	5.2	0.217	7.68	7.72
89.5	2.93	2.53	4.8	0.259	31.3	20.1	0.76	11.88	6.29
127	4.16	2.13	4.125	0.374	111	71.7	2.16	16.55	4.87
200	6.56	2.18	4.225	0.230	274	192.	5.5	17.65	3.14
Total Mix				0.425					
				Carborundum					
37	1.21	3.17	6.15	0.371	4.25	2.74	0.113	10.2	54.2
18	0.59	3.17	6.15	0.284	.36	0.233	0.0098	3.74	36.4
				Glass Beads					
28	0.918	2.5	4.84	0.192	7.18	0.463	0.02	3.14	10
				Cork					
100	3.28	0.24	0.466	0.282	4.63	2.98	0.124	1.44	2.28
127	4.16	0.24	0.466	0.306	10.3	6.65	0.28	2.15	2.28
200	6.56	0.24	0.466	0.232	30.5	19.7	0.75	2.4	2.28
				Iron Dust					
22	0.721	7.33	14.2	0.326	1.12	0.724	0.0305	7.8	20.9
59	1.935	7.59	14.7	0.334	35.45	22.9	.81	28.7	20.2
89.5	2.93	8.03	15.55	0.342	134	86.5	2.80	43.2	16.9
127	4.16	7.97	15.4	0.258	286	185	5.8	44.3	17.2
200	6.56	7.42	19.35	0.338	1370	884	18	55.5	16.3
Total Mix				0.395					
				Tin Dust					
22	0.721	7.25	13.9	0.405	2.105	1.355	0.0565	14.45	12.87
59	1.935	7.33	14.1	0.398	40.5	26.1	0.965	35.4	11.7
89.5	2.93	7.33	14.1	0.472	167	108	3.9	60.8	20.3
127	4.16	7.33	14.1	0.432	437	282	7.5	57.6	16.6
200	6.56	7.02	13.5	0.480	1825	1180	22.2	71.0	25.2
Total Mix				0.349					

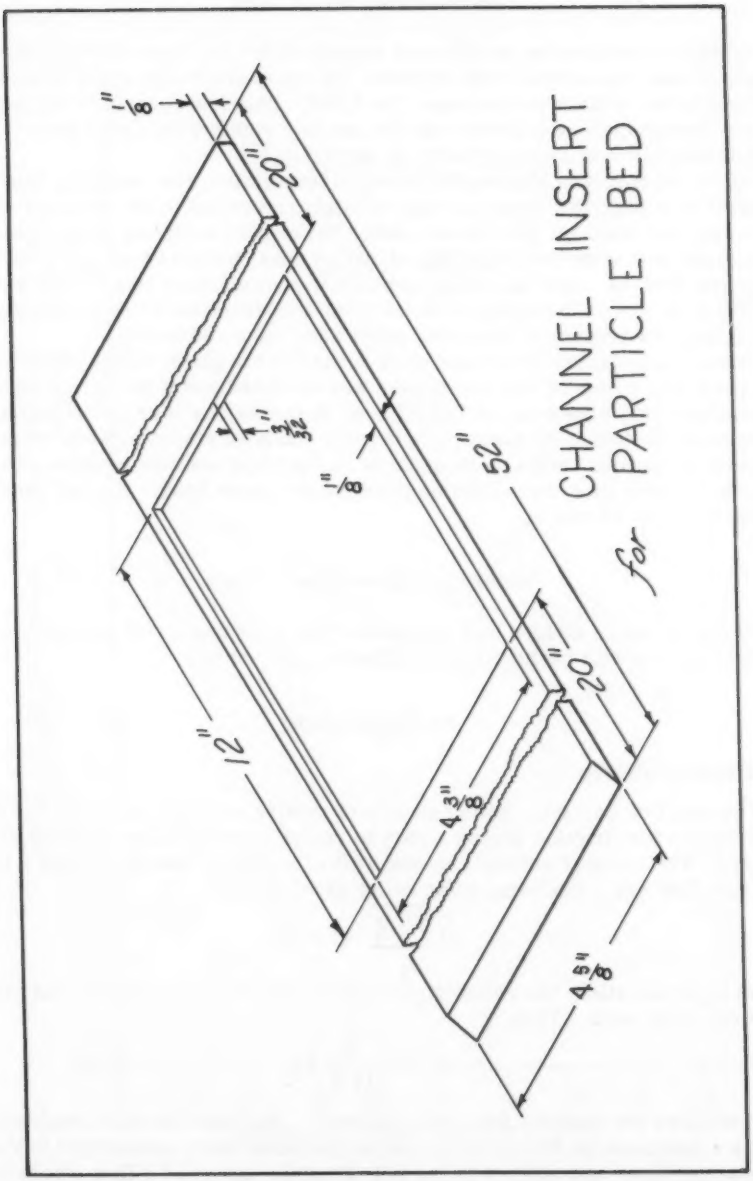


Fig. 9

Procedure for Measuring Concentration Gradients Which Demonstrate Backmixing

When a concentration profile was measured for the case of tin or sand, the selected dust was added to the system. On the average, the ratio of dust volume to the system volume was 1 in 4,850. This low concentration prohibited any coagulation or collision effects and is considerably lower than the one-half of one per cent recommended by Hawksley.(3)

After the dust was thoroughly mixed in the system, the sampling lines were flushed by a sharp air blast and immediately connected to the sampler whose flow rate had been set previously. After the alloted sampling time the collected sample was removed and weighed and an equal weight of material was added to the system. Each sampling position was alternately tested with a selected datum level and deficiencies in the total concentration were corrected by increasing the amount of material added after each removal.

When concentration gradients were made for the glass beads, the mixing chamber was removed and the system was operated under vacuum with the discharge being routed to the bag filters. A continuous feed of the beads was introduced upstream by means of a burette and hose clamp system. Concentrations at various levels were made in an identical manner to those of tin and sand. Data on a concentration gradient for glass beads, tin, and sand are shown in Figs. 10 and 11.

Theory and Discussion of Data

The analysis is divided into two parts: the first deals with re-entrainment and the second with backmixing by diffusion and bounce.

Re-Entrainment

Wall Pickup Theory

The fact that particles rolled or slid in moving on a flat plate led to the observation that friction played a part in resisting the driving force of the air stream. The laminar sublayer on the wall of a channel which carries a turbulent gas flow has a thickness of an order given by (4).

$$\frac{\delta' \sqrt{\tau_o/\rho_g}}{\nu_g} \simeq 11.4 \qquad (1)$$

As an approximation, the velocity gradient in this layer is equal to the velocity gradient at the wall. Thus,

$$v = \left(\frac{\tau_o}{\nu_g \rho_g}\right) y \qquad (2)$$

approximates the velocity field near the wall. For experimental conditions δ' was a minimum of 250 microns and all particles were submerged in this laminar sublayer and subject to the aerodynamic forces of a flow whose velocities are approximated by Eq. (2).

To estimate the aerodynamic force, F_D, acting on a particle resting on the test section floor, it was assumed that 1) the particles were spherical, 2) the floor had no effect, 3) the effective velocity v_o, responsible for the

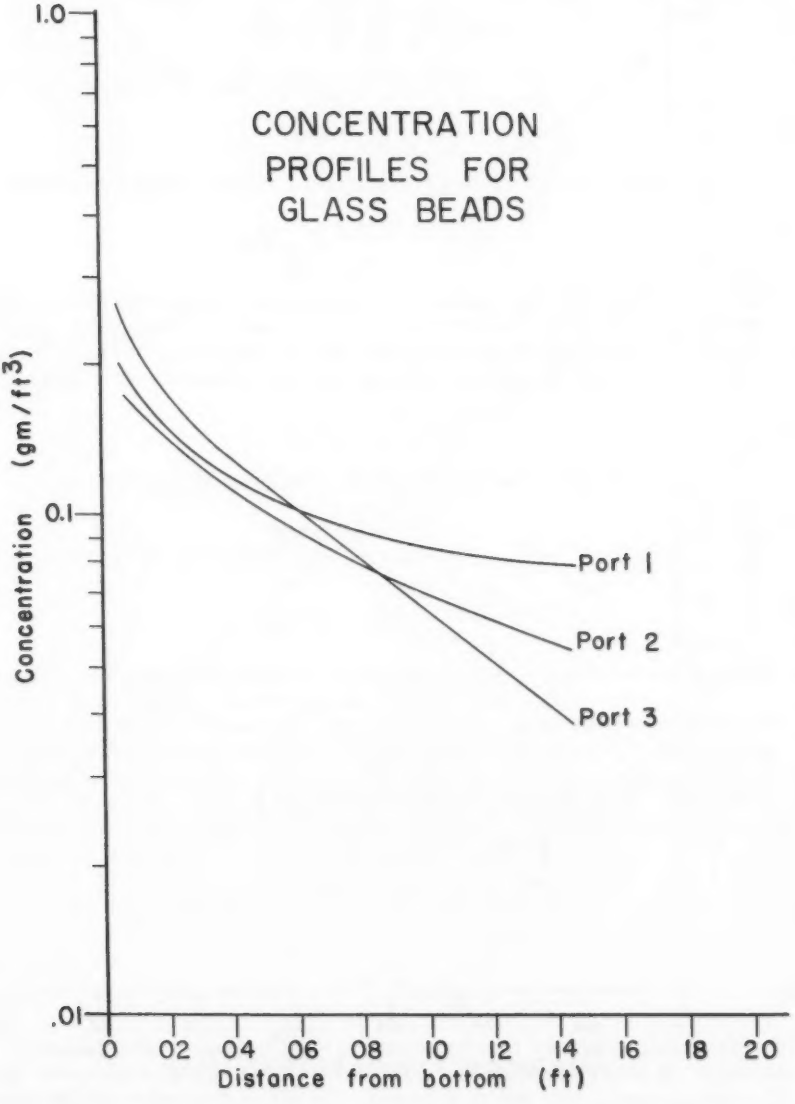

CONCENTRATION
PROFILES FOR
GLASS BEADS
1.0
0.1
.01
Concentration (gm/ft3)
Port 1
Port 2
Port 3
0
02
04
06
08
10
12
14
16
18
20
Distance from bottom (ft)

Fig. 10

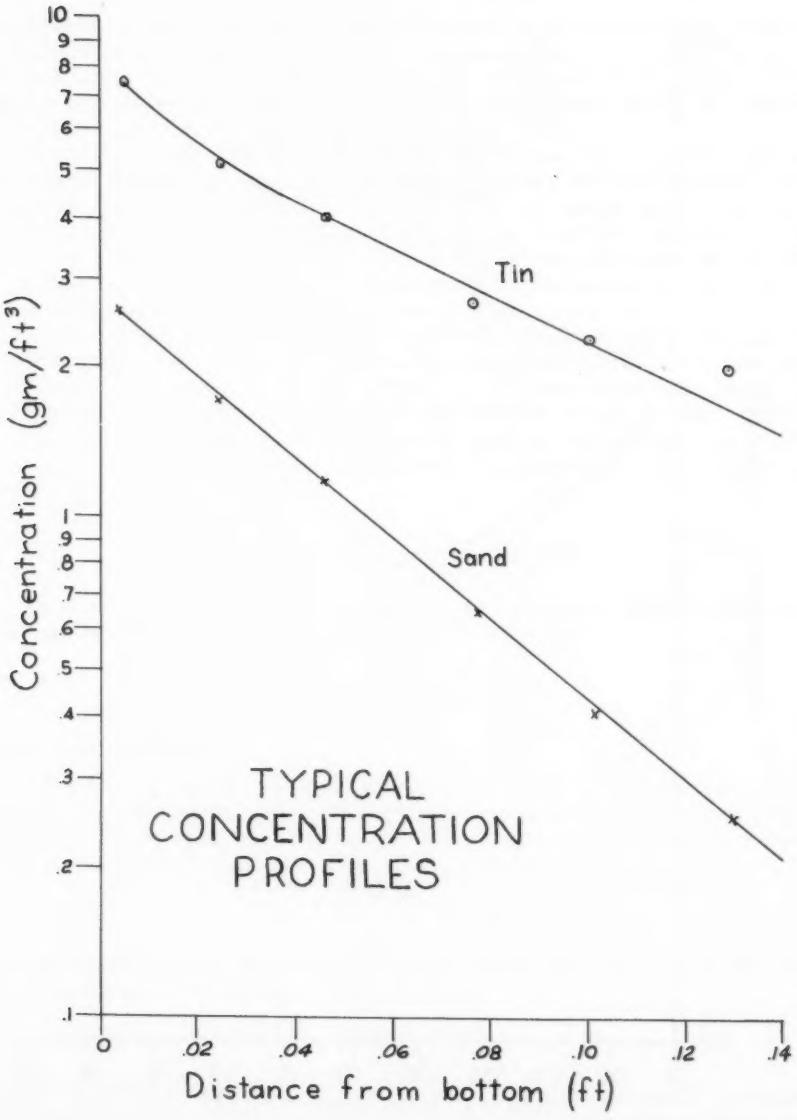

Concentration (gm/ft³)
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
Tin
Sand
TYPICAL
CONCENTRATION
PROFILES
0
.02
.04
.06
.08
.10
.12
.14
Distance from bottom (ft)

Fig. 11

aerodynamic force was v for a y distance of $D_p/2$, and 4) the relationship between F_D and v_o was the same as that for a single sphere in an infinite fluid. In terms of the drag coefficient, C_D, for a sphere

$$F_D = \left(\frac{\rho_g v_o^2}{2}\right)\left(\frac{\pi D_p^2}{4}\right) C_D \tag{3}$$

where according to the assumptions made above

$$v_o = \left(\frac{\tau_o}{\nu_g \rho_g}\right)\frac{D_p}{2} \tag{4}$$

and where for a sphere C_D is a function of the Reynold's number,

$$N_{Re} = \frac{D_p v_o}{\nu_g} = \frac{\tau_o D_p^2}{2\nu_g^2 \rho_g} \tag{5}$$

The aerodynamic force is resisted by a sliding and rolling friction, F_R, which can be written in terms of a combined friction factor, f*, and particle weight. The particle weight, in turn, can be given for the idealized particle in terms of particle diameter, D_p, and specific weight, γ_p, thus,

$$F_R = \left(\frac{\pi D_p^3}{6}\right)\gamma_p f^* \tag{6}$$

The critical value of flow velocity, as measured by τ_o occurs when

$$F_D = F_R \tag{7}$$

Combining Eqs. (3) through (7), it is found that

$$C_D N_{Re}^2 = \frac{4}{3}\left(\frac{D_p^3 \gamma_p f^*}{\nu_g^2 \rho_g}\right) \tag{8}$$

a quantity which depends only on the physical properties of the air and dust in question, in particular, on the special friction factor f*.

The relationship between N_{Re} and $C_D N_{Re}^2$ for spheres is well known.(5) To estimate the critical value of τ_o from known values of f*, it is now only necessary to calculate the value of $C_D N_{Re}^2$, refer to N_{Re}-$C_D N_{Re}^2$ plot, (see Fig. 12), obtain the value of N_{Re} and calculate τ_o via Eq. (10). Since many quantities in the equations are constant for a given condition, the equation reduces to the form of

$$C_D N_{Re}^2 = 0.646 \times 10^{12} \left(D_p^3 \rho_p f^*\right) \tag{9}$$

$$\tau_o = 1.325 \times 10^{-10} N_{Re}/D_p^2 \quad \frac{\text{lb-force}}{\text{ft}^2} \tag{10}$$

A comparison of shear stresses associated with wall pickup and critical shear stresses calculated from friction data is shown in Table II. While the results do not coincide exactly with theory, it is felt that a proper order of magnitude has been established. The many difficulties encountered in operation may have contributed to the source of error. Notable are the inability to preserve a mono-particle layer, the use of graded aggregate causing only larger particles to be contacted by the normal force during friction tests, and improper manometer adjustment in establishing τ_o.

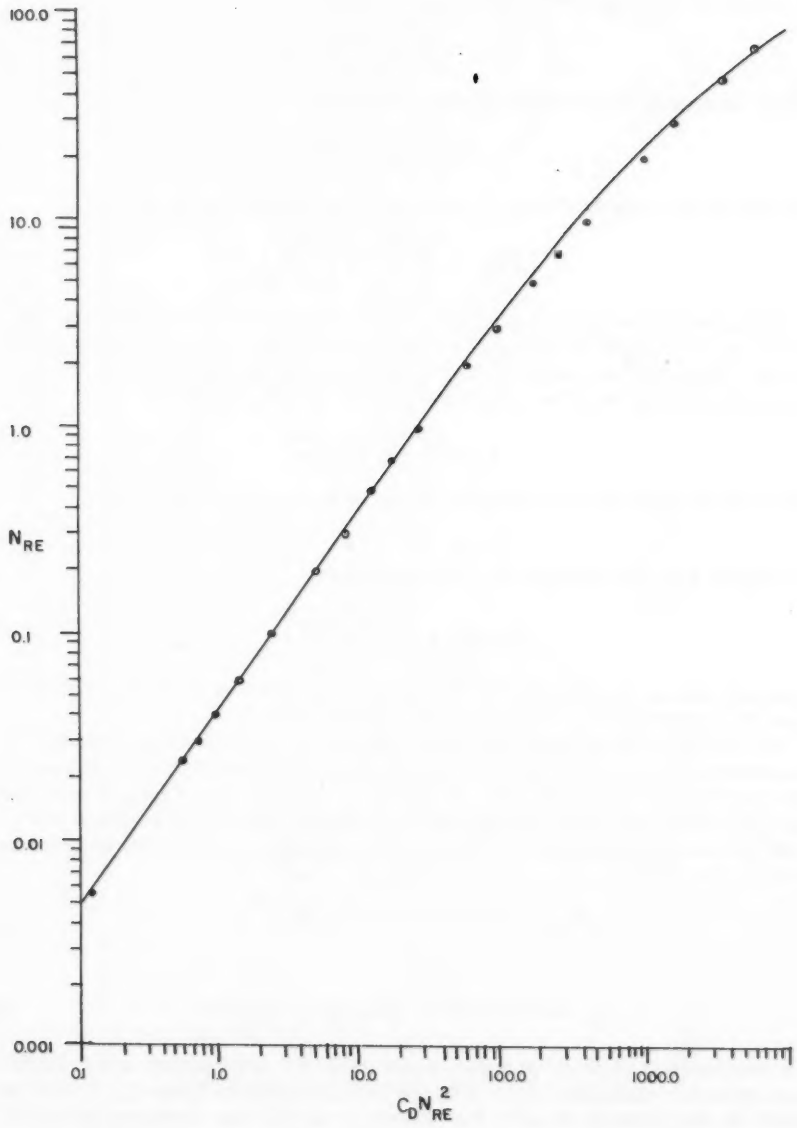


Fig. 12

An experimental study on transport velocity has been made by Baliff, Greenburg and Stern.[6] Conveniently, these men record scour or clean out velocities of some industrial dusts. Since none of their test dusts match any of this investigation, values of friction factor were assumed based on experience with similar types of materials used on this project. With the assumption of the friction factor and being given the particle size and density of the material, the theoretical shear stress was computed. From a relation of shear stress and velocity for the test equipment, the average velocity was computed and compared to those observed by Stern. Comparisons are shown in Table III. Good agreement occurs as is noted in Table III. A large error cannot be incurred as friction factors of the materials tested ranged from two-tenths to five-tenths.

Dust Layer Pickup Theory

In a bed of particles, a particle on top, acted upon by aerodynamic forces, takes the path of least resistance and begins to slide or roll between adjacent

TABLE III

Description Method of Prod.	Sample 1 Foundry non-ferrous wheel abrator	Sample 2 Metal (alum & Bronze Grinding	Sample 3 Steel Shot Blast Cabinet
D_p (microns)	120	100	125
D_p (ft)	4.16×10^{-4}	3.28×10^{-4}	4.16×10^{-4}
D^2_p (ft^2)	17.3×10^{-8}	10.38×10^{-8}	17.3×10^{-4}
D^3_p (ft^3)	71.9×10^{-12}	35.2×10^{-12}	71.9×10^{-12}
Sg	3.02	6.34	6.85
$\rho \left(\frac{lb.sec^2}{ft^4}\right)$	5.85	12.3	13.3
f*	0.4	0.4	0.3
$D^3_p \rho_p f^*$	168.2×10^{-12}	173×10^{-12}	287×10^{-12}
$C_D N^2_{Re}$	103.7	111.5	185
N_{Re}	3.43	3.5	5.4
N_{Re}/D^2_p	10.85×10^6	34.7×10^6	31.2×10^6
τ_o calc. lb/ft^2	26.3×10^{-4}	461×10^{-4}	41.4×10^{-4}
Vel. calc (ft/min)	1360	1800	1720
Vel. observed by Stern et. al. (ft/min)	1650	1560	1900

downstream particles. The forces opposing this motion are friction between the particles (grain interlock), cohesion (if any exists), and gravity. When the particle approaches a higher elevation, the driving force has increased considerably since velocity increases with height and interlock resistance is reduced to sliding or rolling friction of one particle on another. Movement occurs rapidly because of increased forces until the particle hits on an adjacent particle and, like leaving a springboard, jumps out into the stream. Once a few particles are dislodged, a chain reaction of bombardment occurs, and the particle bed disintegrates.

Theoretically, the particles are assumed to be spherical, and the friction factor used is that of internal friction or grain interlock, Ψ. The effective velocity responsible for the aerodynamic force is again assumed to be

$$V_o = \left(\frac{\tau_o}{\nu_g \rho_s}\right) y .$$

A pictorial representation of forces acting on an individual particle appears in Fig. 13. In order for a particle to move over another, the ball must roll or slide up the adjacent particle. This is equivalent to moving up an inclined plane. In addition to the necessity of rolling up and over the downstream particle, friction between the particles is encountered. This friction can be thought of as an additional inclination over which the particle must move. The total inclination must therefore be the sum of the constant contact angle plus the additional inclination due to friction. The angle ϕ as noted on Fig. 13 represents this total inclination.

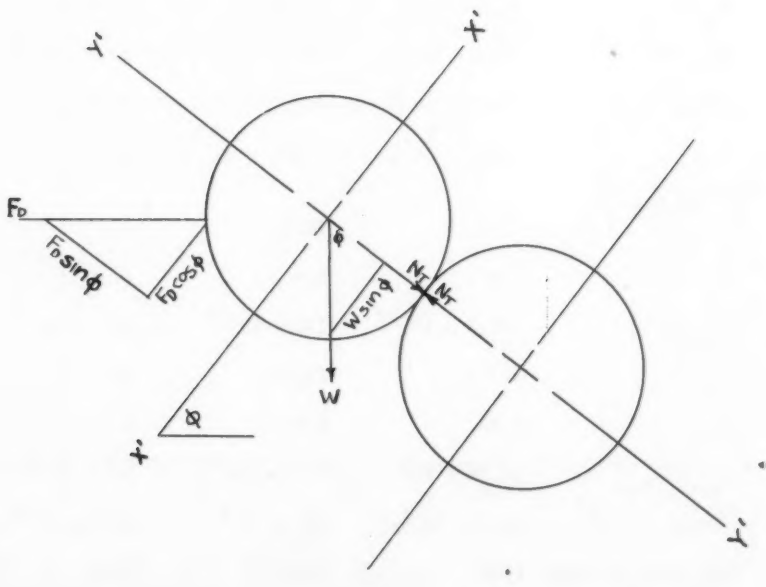


Fig. 13

$$F'_x = 0$$

$$= F_D \cos \phi - W \sin \phi \qquad (11)$$

$$\text{Or} \quad F_D = W \tan (\phi)$$

Tan ϕ is identical to the friction factor obtained from the direct shear test and is denoted as Ψ. In an idealized bed of rhombohedrally packed spheres, which show no cohesion, $\Psi = \tan \phi = \tan 30^\circ$.

A theoretical determination of the critical τ_o is as before (Eqs. (9), (10)) where now f* has the physical meaning of Ψ or ($\tan \phi$).

Theoretical Results

A summary of theoretical shear stresses based on friction factor measurements and observed shear stresses for pickup from particle beds is shown in Table IV. The calculated values of shear stress are generally higher than those observed and may be as much as three times larger. Although this large discrepancy occurs, it is felt that they fall within a reasonable order of magnitude. If velocity is used as a criterion of comparison instead of shear stress, the calculated and observed values are closer together. A complete velocity relationship has been purposely omitted in order to preserve a general nature of solution to this type of problem. A comparison of some observed and calculated values of velocity and shear stress appears in Table V.

In some cases, particularly in the smallest size range of fly ash and carborundum dust, experimental values of shear stress could not be taken since velocities required for pickup exceeded that of the equipment. The velocity of air to keep the material airborne, however, is considerably less than that required to pick it up from the bed.

Difficulties encountered are similar to those of wall pickup with few exceptions, the notable exception being the inability to clean the system before the start of the tests. If one or two or more individual particles tore loose from the upstream housing, these particles could have caused an erroneous reading. Extreme care was taken to avoid such incidents, but the possibility still existed. Once again it was difficult to observe the very small particles.

Pickup from particle layers has also been studied by Shields who treats sediment entrained from river bottoms. The Shields[13] entrainment function, as shown on Fig. 14, is usually presented with abscissa values from one to 1000. The values obtained in this study do not cover the entire range of Shields' work but start in the laminar range of values less than one and overlap slightly.

Essentially, the theory for this work and that of Shields are derived in an identical manner. Extension of the theory has been made here by an attempt to define explicitly the Shields resistance and shape parameter in terms of an internal friction factor Ψ.

Two sets of points are shown on Fig. 14. The squares represent the ordinate parameter as suggested by Shields and the circles represent a corrected Shields' parameter using the internal friction factor Ψ. The closer agreement between the circles and Shields' curve would, according to the present theory, indicate that Ψ for sediment transport is of the order of unity. While both sets of points might be considered to be of the proper order of magnitude, it is felt that closer agreement with Shields might be obtained if the Shields parameter is corrected for internal friction factor. ψ should be obtained in

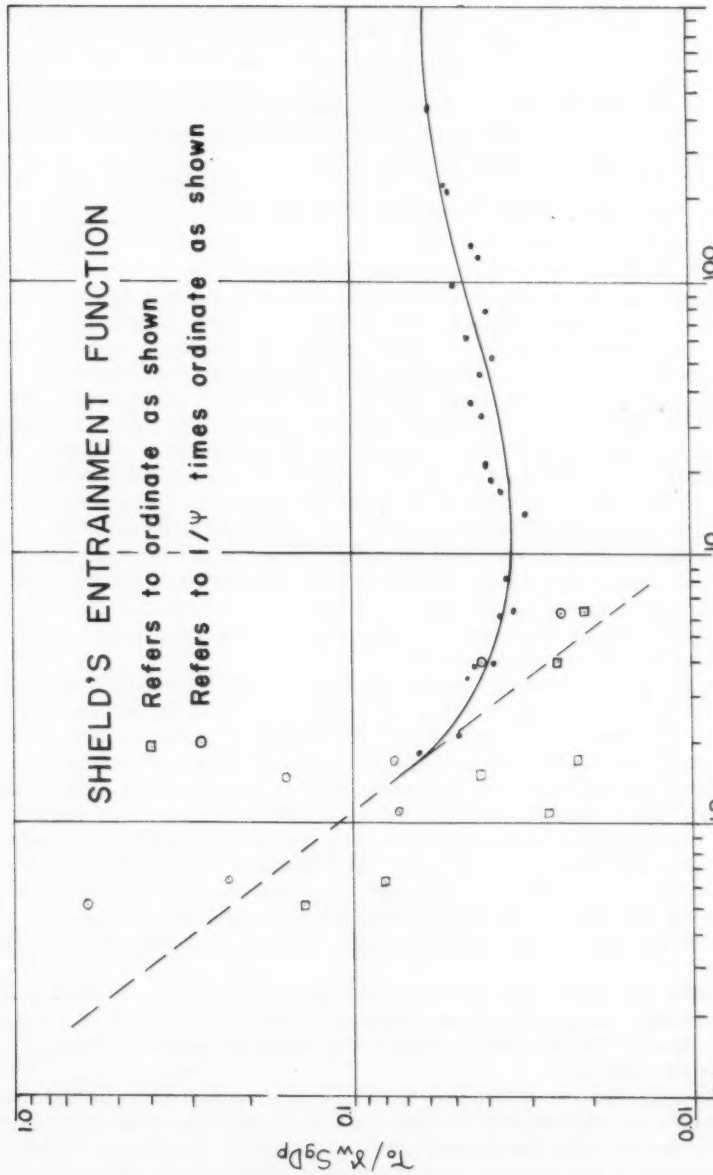

SHIELD'S ENTRAINMENT FUNCTION
□ Refers to ordinate as shown
○ Refers to 1/ψ times ordinate as shown
τo/γw SgDp
Dpu*/ν
0.01
0.1
1.0
10
100

Fig. 14

SA 4

Fig. 14

TABLE IV

PICKUP FROM PARTICLE LAYER

Dust	D Microns	D(ft) x 10^4	Sg	ρ_p	$\tan\phi$ (Ψ)	ϕ degrees	$D_p^3\rho_p$ x 10^9	$C_D N_{Re}^2$	N_{Re}	N_{Re}/D^2 x 10^{-8}	τ_o calc. x 10^4	τ_o obs. x 10^4
U.C.F.A.	505	16.58	1.95	3.78	0.468	25.09	8.04	5200	62	0.226	29.95	13.0
	358	11.72	1.97	3.82	0.467	25.05	2.89	1870	31.2	0.226	29.95	12.0
	272	8.92	1.99	3.85	0.369	20.50	1.01	654	14.3	0.180	23.8	12.2
	200	6.56	2.01	3.95	0.449	24.20	0.50	323	8.3	0.193	25.6	10.7
	127	4.17	2.10	4.07	0.292	16.28	0.0857	55.3	1.90	0.110	14.8	12.0
	89.5	2.94	2.19	4.25	0.400	21.80	0.0435	28.1	1.04	0.120	15.9	10.0
	59.	1.94	2.29	4.43	0.338	18.68	0.0109	7.08	0.295	0.0785	10.4	13.9
	22.	0.72	2.36	4.57	----	----	----	----	----	----	----	----
Cottrell F.A.	200	6.56	2.18	4.22	0.326	18.05	0.388	251	6.9	0.16	21.2	7.4
	127	4.17	2.13	4.13	0.436	23.55	0.1295	83.6	2.73	0.1575	20.9	11.4
	89.5	2.95	2.53	4.80	0.252	14.14	0.0308	19.9	0.76	0.088	11.7	19.5
	59	1.94	2.69	5.21	0.163	9.26	0.0062	4.02	0.168	0.0447	5.92	----
	22	0.72	2.69	5.21	0.0275	1.575	0.00002	0.0129	0.0055	0.0106	----	----
Tin	200	6.56	7.02	13.6	0.845	40.2	3.1	2010.0	32.9	0.765	101.5	59.8
	127	4.17	7.33	14.2	0.623	31.85	6.39	413.0	10.2	0.590	78.4	48.8
	89.5	2.95	7.33	14.2	0.505	26.80	0.183	118.0	3.72	0.431	27.1	45.5
	59	1.94	7.33	14.2	0.589	30.45	0.061	39.5	1.4	0.373	49.5	27.3
	22	0.72	7.25	14.05	0.137	7.79	0.0027	1.75	.074	0.145	19.0	28.0
Iron	200	6.56	7.42	14.35	0.344	19.00	1.39	900	18.2	0.424	55.2	37.5
	127	4.17	7.97	15.45	0.347	19.22	0.386	250	6.9	0.392	52.0	32.5
	89.5	2.95	8.03	15.55	0.399	21.75	0.158	102	3.21	0.372	49.3	23.2
	59	1.94	7.39	14.7	0.367	20.15	0.0393	25.4	0.94	0.250	33.2	23.5
	22	0.72	7.33	14.2	0.424	22.98	0.000843	0.86	0.036	0.0694	18.7	16.25
Cork	200	6.56	0.24	0.466	0.307	17.08	0.0403	26.1	0.97	.0226	3.0	6.4
	127	4.17	0.24	0.466	0.452	24.30	0.01522	9.87	0.41	.0237	3.14	10.5
Carborundum	37	1.21	3.17	6.15	0.330	18.25	0.00359	2.32	0.097	6.65	8.8	19.2
	18	0.59	3.16	6.15	0.263	14.72	0.000332	0.215	0.0091	2.62	3.5	----
Glass	28	0.918	2.50	4.85	0.246	13.81	0.000922	0.597	0.0252	3.0	4.0	21.2

TABLE V

Material U.C.F.A.	Ave.Size (Microns)	Calc.Crit. Velocity ft/sec.	Observed Critical Velocity ft/sec.	Calc ν_o / Obs. ν_o	V Calc = V Obs.(1
	505	22.2	13.0	2.3	1.71
	59	11.1	13.6	1.59	0.82
Cottrell F.A.	200	17.5	8.6	2.87	2.04
	89.5	12.0	17.4	0.60	0.69
Tin	200	42.5	32.5	1.70	1.31
	22	17.0	21.8	0.68	0.61
Cork	200	4.5	7.6	.47	0.590
	127	4.6	11.3	.314	0.411
Carborundum	37	10.0	17.0	.46	0.59
Glass	28	5.4	17.5	0.190	0.320

a manner consistent with its use. For example, Ψ is obtained in an air atmosphere where small amounts of moisture will affect its value through a change in cohesion. If Ψ is obtained under water, viscous effects may also alter its value.

Backmixing

Backmixing by Diffusion

Theory

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + V_t\frac{\partial c}{\partial y} = \mathcal{D}_{eff.}\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right) \qquad (12)$$

is the differential equation for dust concentration in a dusty gas moving in a two-dimensional flow where the particles are acted upon by a separating force which moves them in a negative y-direction at a terminal velocity, V_t, and where there is a backmixing effect that can be written in terms of an effective diffusion coefficient, $\mathcal{D}_{eff.}$ $\mathcal{D}_{eff.}$, can be, and is, a function of x and y.

In the system under study, an x-distance will eventually be reached where $\frac{\partial}{\partial t}$ and $\frac{\partial}{\partial x}$ are zero. Since v is also zero, Eq. (12) reduces to

$$V_t C = \mathcal{D}_{eff_3}\frac{\partial c}{\partial y} \qquad (13)$$

and the flux of particles toward the surface at any level is exactly balanced by backmixing. In Eq. (13), the terminal velocity can be calculated; the concentration and concentration gradient can be obtained from a plot of concentration versus distance from the wall. An "experimental" diffusion coefficient can

then be computed and compared to theoretical values calculated on the basis of different backmixing mechanisms.

A logical mechanism for backmixing of small particles is turbulent diffusion. If backmixing occurs only by turbulent diffusion, that is, the particles follow the turbulent gas motion,

$$\mathcal{D}_{eff} = \mathcal{D}' \tag{14}$$

where $\mathcal{D}'$ is the turbulent diffusion coefficient of the gas.

Because $\mathcal{D}'$ is related to μ', the turbulent or eddy viscosity which can be computed from velocity field data, there are relatively simple methods of estimating $\mathcal{D}'$ in many cases of practical interest. $\mathcal{D}'$ is related to μ' by (7)

$$\mathcal{D}' = \mu'/\rho_g \tag{15}$$

where μ' is defined by

$$\tau = \mu' \frac{du}{dy} \tag{16}$$

Usually, the velocity field can be given in logarithmic form over extended y-distances(8)

$$\frac{u}{u_*} = \frac{1}{b} \ln \frac{y u_* \rho_g}{\mu_g} + \text{Constant} \tag{17}$$

where

$$u_* = \sqrt{\tau_o/\rho_g}$$

and

$$\frac{du}{dy} = \frac{u_*}{by} \tag{18}$$

Combining Eqs. (15), (16), and (18)

$$\mathcal{D}' = \frac{\tau}{\rho_g}\left(\frac{dy}{du}\right) = \frac{\tau by}{\rho_g u_*} \tag{19}$$

For the present case, $\tau = \frac{\tau_o (A-y)}{A}$ and $\mathcal{D}'$ in terms of b, the reciprocal of the slope of the logarithmic plot of the velocity is

$$\mathcal{D}' = by u_* \frac{(A-y)}{A} = by\sqrt{\frac{\tau_o}{\rho_g}}\,\frac{(A-y)}{A} \tag{20}$$

where A is one half of the channel depth.

It is noted that $\mathcal{D}'$ is zero at the wall (y = 0) and in the center of the channel (y = A), "b" has a value of approximately four tenths.(9)

Criterion for Backmixing by Diffusion

Longwell and Weiss,(10) by considering particles in an oscillating velocity field, have developed a convenient criterion concerning conditions for particle diffusion. Approximately, $\mathcal{D}$ eff is of the order of

$$\frac{\mathcal{D}_{eff}}{\mathcal{D}'} = \frac{\left(18\mu_g/\rho_g D_p^2\right)^2}{\omega^2 + \left(18\mu_g/\rho_g D_p^2\right)^2} \tag{21}$$

where ω is an "average" rotational speed of the gas eddies in radians per second. For turbulent diffusion to be the mechanism of backmixing, the ratio of Eq. (21) should be nearly unity. To estimate ω, it was first assumed that the eddy size was one-fourth the height of the channel and that its velocity of rotation would be ten per cent of the mean velocity in the system.(2) Thus, an eddy 0.46" in diameter rotating at five ft/sec. will have a frequency of 130 radians per second.

Calculation Procedure

The experimental diffusion coefficient was calculated as follows: First, an accurate velocity profile was established in the test section before the introduction of each test dust (Fig. 15). The profile was tested again with the dust in the stream. It is notable that the velocity profile did not change appreciably with the addition of particulate matter. This is probably due to the relatively low concentrations used.

With the establishment of the profile, seven equally spaced points were isokinetically sampled for particle concentration and recorded. The values of concentration were then plotted semi-logarithmically against distance from the wall. If a straight line was obtained as for sand, Fig. 11, an expression for the concentration gradient ($\frac{\partial c}{\partial y}$) was readily obtainable. In most cases, however, a linear plot had to be made (see Fig. 16), and the gradient determined by drawing the tangent to the portion of the curve in question and measuring the slope. Needless to say, this method may lead to error but can be used conveniently if reasonable care is used in drawing.

The next step in determining the diffusion coefficient from Eq. (13) is that of determining a value of V_tC or flux. The magnitude of the terminal velocity, however, presents some difficulty since it varies as the particle size changes. It therefore becomes necessary, when a wide range of particle size exists, to determine the cumulative value of V_tC by a microscopic analysis. Essentially the procedure is as follows. From each of the concentration samples taken at a given port, a microscopic particle size count is made of a representative portion of the dust collected. The counted particles are grouped into a size range and analyzed on a weight basis. The middle value of each group in the size range is called the average diameter (D_{ave}). D_{ave} is then cubed and multiplied by the number of particles in the group. The product of D^3_{ave} and the number of particles in the group is then divided by the sum of all ($D^3_{ave}N$) and called V(D). V(D) times the concentration of the level in question times the terminal velocity of the average particle size would then represent the flux attributed to one group of particles in the size range. The total flux for one level is obtained by adding the flux for each group in the range. A typical calculation for tin appears on Tables X and XI. This analysis was not extended to the glass beads due to its rather narrow range of size. Once the flux was established, it was divided by the concentration gradient ($\partial c/\partial y$) to give the observed value of diffusivity. A simpler approach to finding the flux is attained if the mass mean diameter ($\bar{d}m$) is used in conjunction with the terminal velocity. This is particularly true if a narrow size range is encountered.

An example of a concentration profile is shown in Fig. 17. Experimental points show concentration values at various levels for a distance thirteen feet downstream from the entry to the test section. Because the particles are

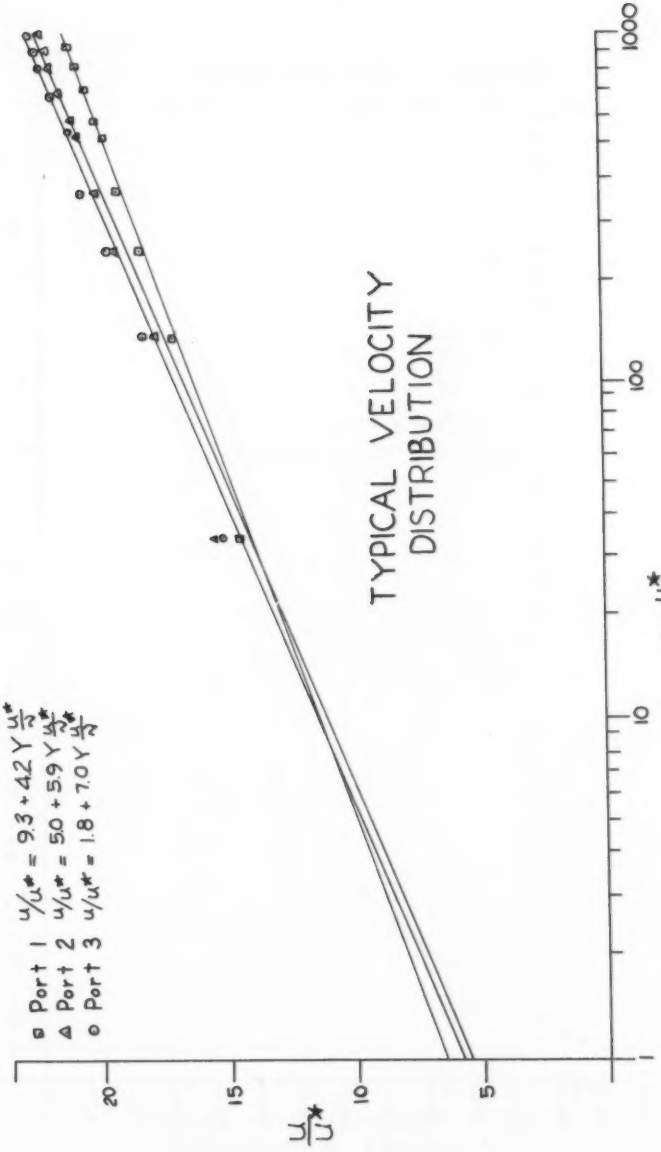

TYPICAL VELOCITY DISTRIBUTION
□ Port 1 u/u* = 9.3 + 4.2 Y u*/ν
△ Port 2 u/u* = 5.0 + 5.9 Y u*/ν
○ Port 3 u/u* = 1.8 + 7.0 Y u*/ν
u/u*
Y u*/ν
5
10
15
20
1
10
100
1000

Fig. 15

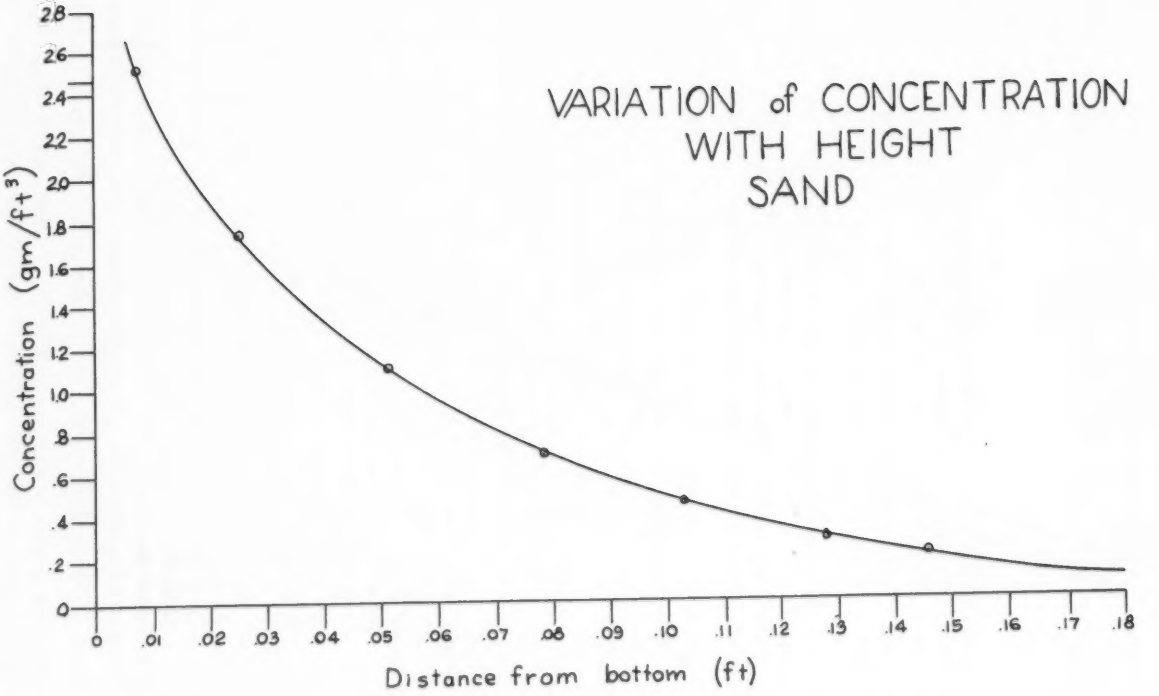


Fig. 16

SA 4

Concentration (gm/ft^3)

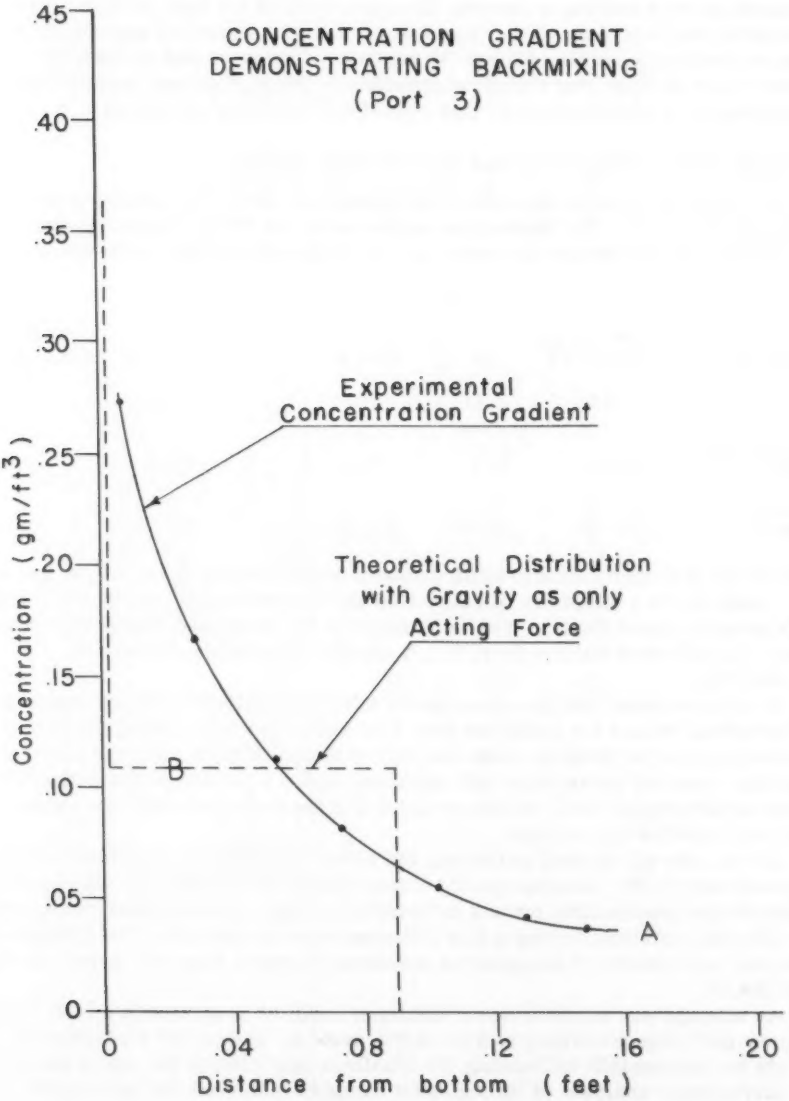

CONCENTRATION GRADIENT
DEMONSTRATING BACKMIXING
(Port 3)
Experimental
Concentration Gradient
Theoretical Distribution
with Gravity as only
Acting Force
B
A
Concentration (gm/ft3)
.45
.40
.35
.30
.25
.20
.15
.10
.05
0
0
.04
.08
.12
.16
.20
Distance from bottom (feet)

Fig. 17

relatively small (glass beads), the concentration gradient is a result of backmixing by turbulent diffusion against gravity. In curve B, the concentration profile is calculated on the basis of gravity separation with laminar flow. If simple gravity settling occurred, the upper part of the test section above a certain level would be void of particulate matter. Repeated experiments have shown that such profiles (Curve A) are always obtained and an attempt has been made to show that turbulent diffusion is the mechanism responsible for concentration distributions of this type if the particles are small.

Comparison of Theoretical and Experimental Results

In order to evaluate the effects of diffusivity, three dust samples were chosen for study. The dusts were subjected to the Weiss-Longwell criterion to determine the diffusivity ratios and the following results were obtained:

TABLE VI

Material	Size Range (Microns)	Sg	D_{ave} Microns	Diffusivity Ratio $\frac{\mathcal{D}_{eff}}{\mathcal{D}'}$
Sand	30-165	2.64	96	.0061
Spherical Tin	30-90	7.3	53.5	.0146
Glass Beads	3.25-39	2.50	25.4	.75

From the diffusivity ratios, little diffusion was expected from the tin and sand.

Table VII is a summary of calculated and observed diffusion coefficients. All samples taken for this test were made at the same distance downstream from the entrance section (port 3). A sample calculation appears on Table VIII.

It is to be noted that the glass beads follow the diffusion theory rather well. Theoretical values for positions one, four and seven are deleted since the correction factor tends to make the values at position four (center line) zero. Position one and seven were not calculated since a portion of the collecting tube is submerged in the boundary layer and the turbulent diffusion equations are not valid for that region.

In the case of the sand particles, the observed diffusion coefficients are approximately six times as much as those calculated by theory. This would indicate that backmixing occurs primarily because of some other mechanism.

The tin particles, having a low diffusion ratio compared to the diffusion of the gas, also exhibited an apparent diffusivity greater than that predicted by the theory.

An attempt was made to see if diffusion could be responsible for distributing the particles according to size in the system. It was felt that diffusion might be responsible for moving the smallest particles to the top of the duct. A microscopic analysis of tin and sand samples indicated that no significant difference occurred in the distribution of particle size in the vertical direction.

Discussion of Data

Errors involved in diffusion calculations may be numerous. The concentration gradient could not be obtained by graphical methods with any degree

TABLE VII

SAMPLE PORT NO. 3

Position	Material-Glass		Material-Sand		Material-Tin	
	Observed $\mathcal{D}$ $ft^2/sec.$	Calculated $\mathcal{D}$ $ft^2/sec.$	Observed $\mathcal{D}$ $ft^2/sec.$	Calculated $\mathcal{D}$ $ft^2/sec.$	Observed $\mathcal{D}'$ $ft^2/sec.$	Calculated $\mathcal{D}_{eff.}$ $ft^2/sec.$
1	.00154	----	.098	----	.0157	----
2	.0123	.0149	.089	.0166	.032	.0135
3	.0153	.0150	.084	.0157	.0545	.0135
4	.0149	----	.0965	----	.0584	----
5	.0158	.0127	.0953	.0157	.055	.0135
6	.0157	.0126	.0953	.0166	.0915	.0135
7	.027	----	.0955	----	.094	----

of precision. Wherever possible, (when the concentration plotted as a straight line on semi-log paper) the equation of the line was determined and the gradient established by taking the first derivative. Another error of considerable note is that of buildup and sloughing of particles in the system giving unusually high concentrations. This effect was reduced to a minimum by repeating each reading at least three times. Other errors may be incurred in weighing, microscopic counts, and positioning of sampling tubes.

Comparison with Other Studies

While a direct comparison of data with other studies is not available, the diffusion theory used in this portion of the study is identical to that derived by Einstein[11] in his work with sediment transport in rivers.

TABLE VIII

CONCENTRATION GRADIENT AND DIFFUSION CALCULATION OF GLASS BEADS

P_t	C	$\frac{y}{x10^3}$	V_t	V_tC	$\frac{\Delta C}{\Delta y}$	$D'_{obs.}$	β	βu_*	$\beta u_* y$	$D_{eff.}$
Port 1										
1	0.1983	7.5	0.18	0.0377	3.25	0.0116	0.48	1.087	0.00816	----
2	0.158	25.6	0.18	0.030	1.995	0.0151	0.48	1.087	0.0278	0.0185
3	0.1135	51.0	0.18	0.0216	1.03	0.0210	0.48	1.087	0.0556	0.0186
4	0.0883	76.7	0.18	0.0168	0.547	0.0307	0.495	1.165	0.0845	----
5	.086	51.0	0.18	0.01635	0.257	0.0635	0.549	1.245	0.0634	0.0212
6	.0815	25.6	0.18	0.0155	0.1035	0.150	0.549	1.245	0.0318	0.0212
7	.0805	7.5	0.18	0.0153	0.0443	----	0.549	1.245	0.00923	----
Port 2										
1	0.117	7.5	0.18	0.0318	1.97	0.0161	0.398	0.884	0.00663	----
2	0.145	25.6	0.18	0.0261	1.52	0.0171	0.398	0.884	0.0226	0.0151
3	0.111	51.0	0.18	0.0200	1.16	0.0171	0.398	0.884	0.0450	0.0151
4	0.863	76.7	0.18	0.0162	0.799	0.0203	0.398	0.884	----	----
5	0.739	51.0	0.18	0.0133	0.606	0.0203	0.392	0.870	0.0444	0.0149
6	0.590	25.6	0.18	0.0106	0.54	0.0196	0.392	0.870	0.0223	0.0149
7	0.493	7.5	0.18	0.0086	0.503	0.0176	0.392	0.870	----	----
Port 3										
1	0.2705	7.5	0.18	0.0488	3.33	0.00147	0.392	0.877	0.00656	----
2	0.1575	25.6	0.18	0.0254	2.30	0.0124	0.392	0.877	0.0224	0.0149
3	0.115	51.0	0.18	0.0207	1.43	0.0145	0.392	0.877	0.0446	0.0150
4	0.0877	76.7	0.18	0.0158	1.122	0.0141	0.361	0.806	0.0616	----
5	0.0654	51.0	0.18	0.0118	0.783	0.0152	0.33	0.74	0.0378	0.0127
6	0.0465	25.6	0.18	0.00835	0.564	0.0148	0.33	0.74	0.0190	0.0126
7	0.0389	7.5	0.18	0.0070	0.259	0.027	0.33	0.74	0.0056	----

Backmixing by Bouncing

Theory

Irregularly shaped particles do not necessarily reflect when they strike a surface but bounce at some angle with a probability distribution about the average angle of reflection.* Because a particle bouncing at a low angle has a certain probability of reflecting at a high angle, irregular bounce is a mechanism of backmixing.

A particle striking a collecting surface at an angle θ with a velocity v_i will be reflected at some angle $(\theta + \alpha)$ with a velocity Ev_i. "α" is the angle of dispersion with a probability distribution about the average angle of reflection. E is equal to or less than unity and represents the elasticity of the bounce. After rebound, the particle will have a y-velocity of $Ev_i \sin(\theta + \alpha)$ which will carry it a certain "stopping distance" away from the surface before the separating force, which is directed toward the surface, can decelerate the particle to a standstill and start it toward the surface once again.

To get an idea of the order of magnitude of backmixing by bounce, a simplified system is considered here. The approach angle is very small ($\theta = 0$); the particle hits with the average velocity of the gas stream ($v_i = V_o$); and the bounce is assumed to be completely elastic ($E = 1$). The dispersion angle is distributed normally about the reflection angle which is zero, dispersion through the surface being reflected away from the surface, such that

$$\frac{2\delta}{\sqrt{\pi}} \exp\left(-\delta^2\alpha^2\right) d\alpha \tag{22}$$

represents the fraction of the total number of bouncing particles which bounce at an angle between α and $d\alpha$.

The velocity away from the surface becomes

$$V_y = V_o \sin\alpha \approx V_o\alpha \tag{23}$$

where α is a small angle less than 15°. It is further assumed that the stopping distance of a particle bouncing at an angle is governed by Stoke's resistance law.

It is now assumed that at every y-distance above the surface, particles falling toward the surface are falling with their terminal velocity. This is certainly not true of particles whose bounce carry them only to this level, but the concentration at this level is made up primarily of particles "raining down" from much higher levels.

At equilibrium a flux balance at a certain level reads

$$CV_t = \int_{\alpha}^{\infty} C_w V_t \frac{2\delta}{\sqrt{\pi}} \exp\left(-\delta^2 \alpha^2\right) d\alpha \tag{24}$$

where the first term represents the flux toward the wall caused by the separating force and the integral term represents the flux away from the surface of those particles which have stopping distances greater than the y level in question. $C_w V_t$ is the flux of particles into the surface; $\frac{2\delta}{\sqrt{\pi}} \exp(-\delta^2 \alpha^2) d\alpha$

*See special tests demonstrating backmixing properties, p.

is the fraction of particles bouncing at an angle α, reaching a stopping distance $S_s = y$ and $\delta = \frac{1}{\sigma m}$.

Rearranged, Eq. (24) gives

$$\frac{C}{C_w} = 1 - \text{erf}(q) = 1 - \frac{2}{\sqrt{\pi}}\left(q - \frac{q^3}{3.1!} + \frac{q^5}{5.2!} - \frac{q^7}{7.3!} + \cdots\right) \tag{25}$$

where $\text{erf}(q) = \int_0^q e^{-q^2}\, dq$

(probability or error function) and

$$q = \alpha\delta \tag{26}$$

The effective diffusion coefficient becomes

$$\mathcal{D}_{eff} = \frac{V_t C}{\frac{dc}{dy}} \tag{27}$$

Since α cannot be obtained explicitly in terms of y, the effective diffusion coefficient must be obtained by graphical differentiation of a plot of $C = C(y)$.

Calculation Procedure

Since reliable data on the dispersion angle of small particles with low approach angles could not be obtained, this information was calculated from the concentration profiles in the following manner: From a point of known y-distance from the wall, the concentration was obtained and placed into Eq. (25). The known y represented a related stopping distance to the angle of rebound α which was required to bounce a particle to that height. A similar procedure was followed for a second point. Two equations were now available with the unknowns Cw and q, where $q_1 = \alpha_1\delta$, and $q_2 = \alpha_2\delta$. By dividing the resulting equations, an expression for δ may be obtained for each type of particulate matter in question. Once δ is established, Eq. (25) can then be used to establish the concentration at the wall and resulting concentrations at other levels. It is to be noted that δ is constant for a given material but α varies from level to level and is related to S_S, the stopping distance, since $S_S = S_S(\alpha)$. The relation between the stopping distance S_S and α, the rebound angle necessary to convey a particle to that height appears on Fig. 18. Sample computations appear in Appendix A.

Comparison of Theoretical and Experimental Results

A comparison of theoretical and experimental concentration data appears on Table IX. With the exception of concentrations adjacent to the wall, the values observed and calculated are almost identical. It must be borne in mind however, that close agreement exists throughout the entire depth of suspended material (with the exception of that area near the wall), while only two points on the observed gradient have been used as match points to obtain a theoretical curve. Once "δ" has been established for a given material, however, only one concentration in the stream must be known in order to find the entire gradient. The comparison of diffusion coefficients is not exact but definitely establishes an order of magnitude.

TABLE IX

SUMMARY OF BOUNCE DATA

ANGULAR TIN

$\bar{d}_m$ = 50 microns

Sg = 7.3

δ = 0.2825/degree

Y (ft)	Obs. Conc. gm/ft^3	Calc. Conc. gm/ft^3	Obs. $\mathcal{D}'$ ft^2/sec	Calc. $\mathcal{D}_{eff}$ ft^2/sec
0.0075	7.0	5.35	.0157	.0527
0.0256	4.37	4.38	.032	.092
0.054	3.35	3.33	.0545	.095
0.0767	2.5	2.56	.0584	.0901
0.102	1.95	1.98	.055	.098
0.1275	1.42	1.515	.0915	.101
0.1458	----	1.255	.094	.0968

ROUNDED TIN

$\bar{d}_m$ = 50 microns

Sg = 7.3

δ = 0.547/degree

Obs Conc. gm/ft^3	Calc. Conc. gm/ft^3	Obs. $\mathcal{D}'$ ft^2/sec	Calc. $\mathcal{D}_{eff}$ ft^2/sec
7.64	3.38	Data not available	
2.62	2.07	" " "	
1.00	0.994	" " "	
0.437	0.43	" " "	
0.18	0.207	" " "	
0.093	0.0925	" " "	
0.067	0.507	" " "	

ANGULAR SAND

$\bar{d}_m$ = 93 microns

Sg = 2.64

δ = 0.275/degree

Obs. Conc. gm/ft^3	Calc. Conc. gm/ft^3	Obs. $\mathcal{D}'$ ft^2/sec	Calc. $\mathcal{D}_{eff}$ ft^2/sec
2.54	2.63	.098	.0383
1.75	1.75	.089	.0512
1.099	1.08	.084	.0563
0.654	0.627	.0965	.0527
0.398	0.397	.0953	.0553
0.259	0.219	.0953	.0503
0.204	0.167	.0955	.0567

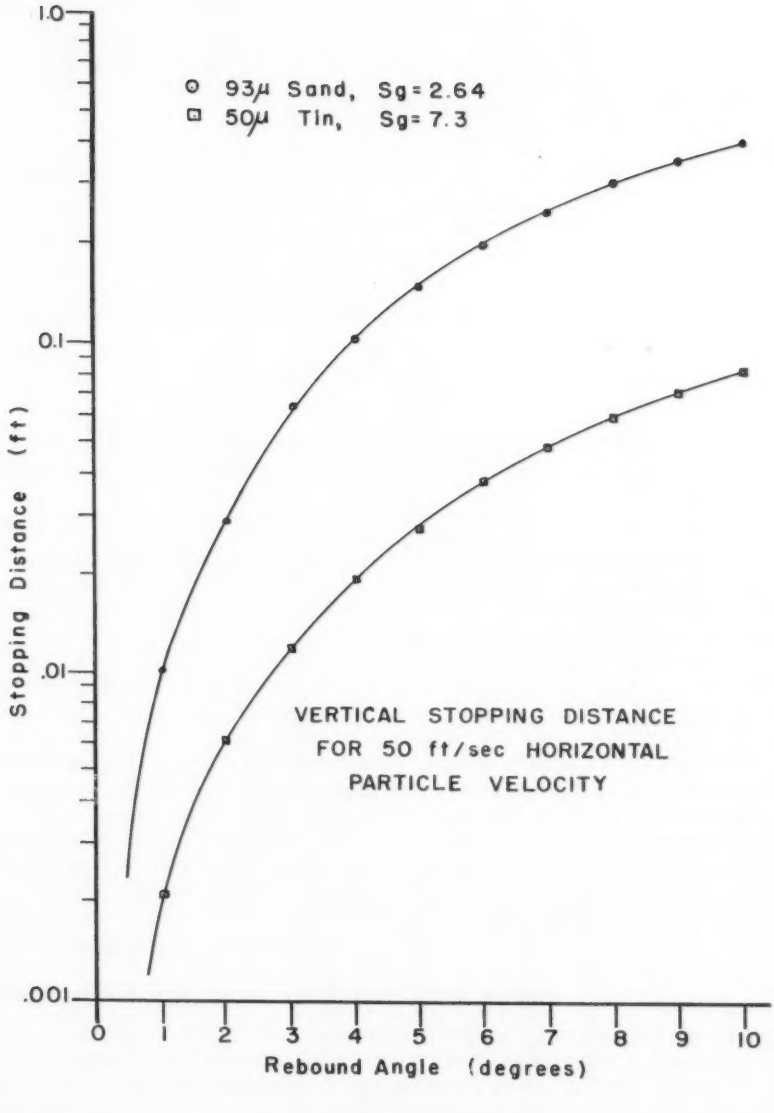

1.0
0.1
.01
.001
Stopping Distance (ft)
o 93μ Sand, Sg = 2.64
□ 50μ Tin, Sg = 7.3
VERTICAL STOPPING DISTANCE
FOR 50 ft/sec HORIZONTAL
PARTICLE VELOCITY
0 1 2 3 4 5 6 7 8 9 10
Rebound Angle (degrees)

Fig. 18

Discussion of Data

The close correlation between observed and theoretical data as shown on Table IX would indicate the validity of the proposed theory. Values of concentration near the wall which show a large difference might be due to: 1) errors in sampling near the wall, 2) the inability to determine the exact concentrations at the wall, 3) the formation of a moving "bed load" at the wall.

In number one, perfect isokinetic sampling in the vicinity of the floor is almost impossible due to the large change of velocity with change of height. In actual procedure, the stream velocity which occurs at the center of the sampling probe was used leaving the lower half of the tube sampling at a rate much higher than conditions warrant due to a rapidly decreasing velocity as the wall was approached. At other sampling points above the floor, the velocity gradient is not so steep and an isokinetic conditions is maintained fairly well.

The inability to determine exact concentrations at the wall is due to wall thickness of the sampling probe. When the probe was lowered to and resting on the floor, the wall thickness of the probe was the limit in the approach to the bottom.

The formation of a bed load in the laminar boundary layer immediately above the channel floor may also intensify differences between observed and calculated values. If such a moving bed load existed, concentrations near the bottom would be considerably higher than the rest of the flow stream and are not accounted for in the bounce theory.

Of particular note, is the fact that the δ values for the angular materials were very close to each other. Since only two materials were tested, a conclusive statement cannot be made but the important significance is implied. On the other hand, the δ value for the rounded particles had a smaller dispersion which is to be expected from a rounded particle.

Perfectly spherical particles might be expected to have an average rebound angle very close to zero but channel roughness may cause a significant dispersion.

Comparison with Other Studies

With the exception of Bagnold,[2] who briefly deals with the height that large sand particles rebound from very rough surfaces, work of this nature is not cited in the available literature.

Special Tests Demonstrating Bounce Properties

In order to gain some knowledge of bounce characteristics, a crude model test was devised. Essentially, the test consisted of shooting distorted ping-pong balls from an air gun at various angles and recording the rebound angles. The gun used is shown on Fig. 19. The distorted balls, which represented irregular particles, were made by boiling plastic balls slightly smaller than an ordinary ping-pong ball.

The gun was fired in different positions from horizontal to 40° and bounce angles were obtained by markings through carbon paper at points of contact on the horizontal surface and a vertical backboard.

That the shapes representing the particles were of a random configuration was borne out by a statistical calculation involving the Null Hypothesis.[12] Essentially, five representative shapes were fired about 50 times each from a

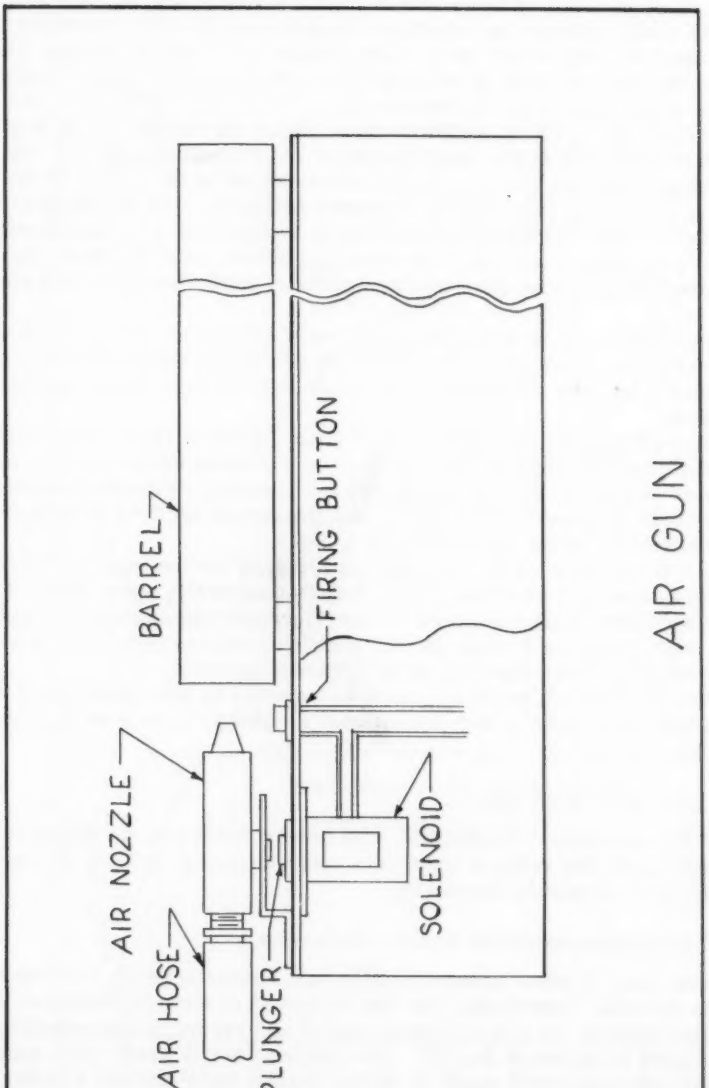

AIR GUN
BARREL
FIRING BUTTON
AIR NOZZLE
AIR HOSE
PLUNGER
SOLENOID

Fig. 19

constant gun angle and each shape showed a very high degree of correlation with each other although visual observation showed them to be of a completely different configuration.

When the data from different gun angles were assembled, it was found that the dispersion angle varied with the incident angle.

An attempt was made to see if any relation existed between positive deviations from the mean rebound angle. The positive angles were chosen since a negative rebound angle could not exist in the test system. It was found that the standard deviation varied from approximately ten degrees for a gun angle of forty degrees to five and one-half degrees for a gun angle of ten degrees (see Fig. 21).

Although no correlation existed for various approach angles, it was found that the mean rebound angle was approximately equal to the approach for incident angles less than twenty degrees and that the total distribution for any given gun angle was very close to a normal distribution (see Fig. 20).

It would appear that information gathered from this model study could easily be adapted for use in a field unit where the separating force is considerably larger than simple gravity. The cyclone, for example, might induce forces causing a twenty micron particle to approach the collecting surface at forty-five degrees.

CONCLUSIONS

Theory predicts quite well the shear stresses and velocities which accompany pickup from a wall or particle layer. Of particular note is the fact that the velocities or shear stresses can be predicted from a few simple bench top experiments on the dust in question, and a knowledge of flow conditions in the system.

Backmixing by turbulent diffusion occurs for small particles if the proper turbulence conditions exist. If the Weiss-Longwell criterion for diffusion produces a diffusion ratio close to unity, backmixing by turbulent diffusion can be expected. The concentration gradient can be predicted with a fair degree of accuracy if the velocity profile is known and one point of concentration.

Bouncing of the particles in a gas suspension would seem to govern the condition of backmixing in the case of larger particles. A concentration field, based on the normal distribution of bounce angle and model data, can be predicted rather accurately if one point of concentration is known.

While all of the proposed theories for this work have been developed for simple cases, modifications can be made for their application to more complex systems.

Appendix A

Sample Calculation of Sand Concentration by Bounce

In the determination of δ from observed data, best agreement with theory was found when the concentrations used in Eq. (25) were those somewhere near midstream whose values fell on, or very close to, the straight section of the line of best fit of log c versus y.

From log c versus y, concentrations of $c_1 = 1.75$ gm/ft^3 at $y = .0256$ ft and $c_2 = 0.398$ at $y_2 = 0.102$ ft. The minimum rebound angle α which is necessary

DISPERSION RELATION WITH INCIDENT ANGLE BASED ON MODEL STUDY
Incident Impact Angle (degrees)
Standard Deviation (degrees)

Fig. 21

TYPICAL REBOUND ANGLE DISTRIBUTION
Frequency
Rebound Angle (degrees)
actual distribution curve
normal distribution curve
mean angle 14.8°

Fig. 20

for the conveyance of a particle to that height is obtained from Fig. 18 and $\alpha_1 = 1.75°$, and $\alpha_2 = 4°$. Writing Eq. (14) twice and dividing one by the other the following is obtained

$$\frac{c_1 = 1 - \text{erf}\ (1.75\delta)}{c_2 = 1 - \text{erf}\ (4.0\delta)}$$

or

$$4.4 = \frac{1 - \text{erf}\ (1.75\delta)}{1 - \text{erf}\ (4.0\delta)}$$

By assuming a value of delta (δ), the error function can be integrated. The assumed values of delta are continued until the right hand side of the equation is equal to the left. Conveniently, the error function or probability integral is computed in most tables of integrals (21) and a fast solution is obtained.

The solution for δ in Eq. (1) yields $\delta = 0.2825$, and $1 - \text{erf}\ (1.75\delta)$ is equal to 0.48479. The concentration at the wall can now be found by substitution in the original equation (Eq. (24)).

$$\frac{C}{C_w} = 1 - \text{erf}\ (\alpha\delta)$$

$$C_w = \frac{1.75}{0.48479} = 3.63$$

The computation of the concentration profile is best shown in tabular form and is as follows:

y ft.	α degrees	q ($\alpha\delta$)	1 - erf (q)	Conc. (Calc.)	Conc. (Obs.)
.0075	.367	.245	.72898	2.63	2.54
.0256	1.75	.494	.48479	1.75	1.75
.051	2.6	.735	.2986	1.08	1.099
.0767	3.4	.961	.17413	.627	.651
.102	4.0	1.13	.11033	.397	.398
.1275	4.7	1.327	.06056	.219	.259
.1458	5.0	1.41	.04615	.167	.204

REFERENCES

1. Lambe, W. T., Soil Testing for Engineers, New York: John Wiley and Sons, Inc., 1951, pp. 88-90.
2. Bagnold, R. A., The Physics of Blown Sand and Desert Dunes, London: Methuen and Co., Ltd., 1954.
3. Hawksley, P. G. W., "Fluid Dynamics and the Stokes Diameter," Monthly Bulletin, British Coal Utilization Research Association, Vol. XV, No. 4, Review Series 102, April 1951, p. 129.

TABLE X

TIN, PORT 3

FLUX CALCULATION BY MICROSCOPIC PARTICLE COUNT

Size Range M	$\frac{D_{ave}}{14}$	$\left(\frac{D_{ave}}{14}\right)^3$	No	$\left(\frac{D_{ave}}{14}\right)^3$ No	V(D)	V_t	Point 1 Flux $(V(D)V_tC)$	Point 2 Flux $(V(D)V_tC)$	Point 3 Flux $(V(D)V_tC)$	Point 4 Flux $(V(D)V_tC)$	Point 5 Flux $(V(D)V_tC)$	Point 6 Flux $(V(D)V_tC)$	Point 7 Flux $(V(D)V_tC)$
0-24.5	0.875	----	----	----									
24.5-31.5	2.0	8.0	23	184	.0042	0.7	.0225	.00786	.002908	.00123	.000508	.000274	.000198
31.5-38.5	2.5	15.65	38	594	.0132	1.0	.1010	.03520	.013090	.00563	.002285	.001233	.000892
38.5-45.5	3.0	27.0	310	8360	.1360	1.3	1.8500	.66250	.239500	.10100	.041750	.022600	.016280
45.5-52.5	3.5	42.8	168	7200	.1602	1.7	2.0850	.72800	.271000	.11400	.047200	.025720	.018400
52.5-59.5	4.0	64.0	285	18250	.4070	2.2	6.8500	2.39000	.886000	.37400	.149000	.083500	.060400
59.5-66.5	4.5	91.1	35	3180	.0709	2.6	1.4100	.49200	.182000	.07690	.031800	.017200	.012420
66.5-73.5	5.0	125.0	43	5380	.1197	3.0	2.7400	.91900	.33100	.13950	.059500	.032200	.023200
73.5-80.5	5.5	166.2	1	166	.0037	3.4	.0962	.03355	.012450	.00526	.002175	.001174	.000848
80.6-87.5	6.0	216.0	7	1510	.0336	3.8	.9770	.34000	.126500	.05340	.022100	.011900	.008610
			910	44824	.9984		16.1117	5.60811	2.064448	0.87092	0.356318	0.195801	0.141248

$$V(D)_m = \frac{\left(\frac{D_{ave}}{14}\right)^3 No}{\sum\left(\frac{D_{ave}}{14}\right)^3 No}$$

TABLE XI

TIN

PORT 3

Pt.	C_3 g/ft^3	Flux* $V_t C$	$\frac{\partial C}{\partial Y}$	Obs. $\mathcal{D}$	β	βu_*	Y x 10^{-3}	$\beta u_* Y$	$\mathcal{D}'$
1	7.64	16.11	1030.	.0157	0.36	0.793	7.5	0.00595	----
2	2.67	5.61	175.0	.032	0.36	0.793	25.6	0.0203	.0135
3	0.992	2.06	37.8	.0545	0.36	0.793	51.0	0.0404	.0135
4	0.418	0.871	14.95	.0584	0.36	0.793	76.7	0.0607	----
5	0.173	0.356	6.5	.055	0.36	0.793	51.0	0.0404	.0135
6	0.0934	0.196	2.14	.0914	0.36	0.793	25.6	0.0203	.0135
7	0.0675	0.141	1.5	.094	0.36	0.793	17.58	0.00595	----

*As calculated by microscopic particle count.

$$\mathcal{D}' = \beta u_* Y \left(\frac{\mathcal{D} - Y}{\mathcal{D}} \right)$$

4. Eshbach, O. W., Handbook of Engineering Fundamentals, 2nd ed., New York: John Wiley and Sons, Inc., 1952, pp. 6-45.

5. Lapple, C. E., et al., Fluid and Particle Mechanics, Newark, Del.: University of Delaware, 1956, pp. 290-293.

6. Baliff, J., Greenberg, L., and Stern, A. C., "Transport Velocities for Industrial Dusts, An Experimental Study," Monthly Review, Division of Industrial Hygiene and Safety Standards, New York State Dept. of Labor, Vol. 28, No. 12, Dec. 1949.

7. Eshbach, O. W., Handbook of Engineering Fundamentals, 2nd ed., New York: John Wiley and Sons, Inc., 1952, pp. 6-10.

8. Hunsaker, J. C., and Rightmire, B. G., Engineering Applications of Fluid Mechanics, New York: McGraw-Hill Book Co., Inc., 1947, pp. 143-144.

9. Prandtl, L., Essentials of Fluid Dynamics, New York: Hafner Publishing Co., 1952, pp. 121-130.

10. Longwell, J. P., and Weiss, M. A., "Mixing and Distribution of Liquids in High-Velocity Air Streams," Industrial and Engineering Chemistry, Vol. 45, March 1953, p. 667.

11. Einstein, H. A., The Bed Load Function for Sediment Transport in Open Channel Flows, U. S. Dept. of Agriculture, Tech. Bull. No. 1026, September 1950.

12. Smith, G. M., A Simplified Guide to Statistics, New York: Rinehart and Co., Inc., 1957, pp. 55-63.

13. Shields, A., "Cited By Rouse, H., Engineering Hydraulics, New York: John Wiley and Sons, Inc., 1949, pp. 789-793.

List of Symbols

A - Constant equal to half the channel depth

b - Constant

C - Concentration (gm/ft^3)

C_w - Concentration at wall (gm/ft^3)

C_D - Coefficient of drag

D_p - Diameter of particle (ft) except where noted different

$\mathcal{D}'$ - Actual diffusion coefficient (ft^2/sec)

$\mathcal{D}_{eff}$ - Effective diffusion coefficient (ft^2/sec)

E - Coefficient of restitution

erf - Error function

f* - External friction factor

F_D - Aerodynamic force (gm or lb force)

F_R - Sliding and rolling friction force (gm or lb force)

N_{Re} - Reynold's number

Pt. - Point, refers to height in channel

q - $\alpha\delta$

S_s - Stopping distance (ft)

Sg - Specific gravity

u - Velocity in x direction (ft/sec)

U* - Friction velocity (ft/sec)

vo - Effective velocity (ft/sec)

V(D) - Mass fraction

V_t - Terminal velocity (ft/sec)

vi - Incident velocity (ft/sec)

W - Weight of particle (lb)

y - Distance measured from bottom wall of channel (ft)

α - Dispersion angle (degrees)

β - Constant, same as b

ΔP - Pressure difference ($P_2 - P_1$) (inches of water)

δ' - Boundary layer thickness (ft)

δ - Constant equal to $1/\sigma m$ (degree^{-1})

μ' - Turbulent viscosity ($\frac{lb\ sec}{ft^2}$)

μg - Gas viscosity ($\frac{lb\ sec}{ft^2}$)

ν - Kinematic viscosity ($\frac{ft^2}{sec}$)

ω - Angular velocity (rad/sec)

ϕ - Friction angle (degrees)

ψ - Internal friction factor

ρp - Particle density ($\frac{lb\ sec^2}{ft^4}$)

ρg - Gas density ($\frac{lb\ sec^2}{ft^4}$)

σm - Standard deviation (degrees)

τ - Shear stress (lb/ft^2)

τo - Shear stress at wall (lb/ft^2)

Other symbols are defined at the point of use.

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

OPERATION OF A 7-MILE DIGESTED SLUDGE OUTFALL*

Norman B. Hume,[1] F. ASCE, Robert D. Bargman,[2] F. ASCE,
Charles G. Gunnerson,[3] M. ASCE and Charles E. Imel,[4] A.M. ASCE

ABSTRACT

Engineering and oceanographic factors which established the design and construction criteria for Los Angeles' digested sludge outfall are reviewed. One year's experience shows that the operation, involving discharge of about 5 mgd of digested sludge and plant effluent into 320 feet of water, has fulfilled the expectations of the designers.

INTRODUCTION

Since the inception of the industry the disposal of the solid products of sewage treatment processes has been a bothersome problem. The problem has been intensified of late by the pressure of rising costs and declining availability of land for historic processes. New materials and construction techniques have opened the door to new extensions of old techniques and made possible disposal practices once thought not desirable.

The City of Los Angeles disposes of sewage from the city proper and 16 surrounding municipalities through the Hyperion Treatment Plant.

Design capacity for the existing plant, placed in operation in 1950, is 245 MGD with present flow being about 270 MDG. Solids disposal methods included digestion, elutriation and mechanical dewatering facilities, utilizing vacuum filtration and flash drying equipment.

Note: Discussion open until December 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2089 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. SA 4, July, 1959.

* Presented at the October, 1958 ASCE Convention in New York, N. Y.

1. Assistant Director, Bureau of Sanitation, Los Angeles, Calif.
2. Assistant Engr.-Superintendent, Hyperion Treatment Plant, Los Angeles, Calif.
3. Civ. Engr., Bureau of Sanitation, Los Angeles, Calif.
4. San. Eng. Associate, Hyperion Treatment Plant, Los Angeles, Calif.

Sludge Disposal Practice in Los Angeles

At the time of design of the plant, it was considered that the revenue received from the fertilizer produced would result in the most economical sludge disposal. In actual practice the fertilizer contains 2% nitrogen and disappointing revenues of only $4.00 per ton are obtained. Costs of production for the fiscal year 1956-57 are shown in the following table and represent minimum chargeable items.

Production of digested sludge, tons/day	160
Digested sludge removed in mechanical dewatering plant, tons/day	92
Cost/ton solids removed in mechanical dewatering plant:	
Elutriation	$1.15
Filtration	6.35
Drying	4.02
Fertilizer handling	2.70
TOTAL	$14.22

Power costs (power consumed is surplus power), fuel charges (digester gas is available), local administrative and general city overhead (including retirement) charges are not included in this table. Such charges would materially increase the figure shown.

The solids escaping capture in the elutriation system were of major concern. Of the 160 tons per day of digested sludge produced, only 92 tons per day were recoverable in the best year of operation and the remaining 68 tons per day escaped to sea via the one-mile ocean outfall. Such disposal was at best undesirable since it was necessary to disinfect the plant effluent using chlorine. In addition, the turbidity of the nearshore waters was significantly increased, and the deposition of solids upon the floor of the Bay contributed to the observed effect upon bottom dwelling animals as discussed in a succeeding paragraph. This major process failure has been presented elsewhere in detail.(1)

Air pollution is of major import in the Los Angeles area. It is indeed strange that man sometimes exchanges one pollution problem for another, but this is precisely what happened in this case. Severe limitations of particulate matter emission from any municipal or industrial plant are imposed. A sliding scale is used as a control measure depending on the process weight, (i.e., pounds per hour processed), with the upper limit being 40 pounds per hour of particulate matter allowed. Average emission of one of the drier units at Hyperion has been about 80 pounds per hour. In addition, the stack effluent poses other problems of odor, visibility, etc.

In 1954 the City was faced with the necessity of expanding facilities consistent with the City's growth. Consulting engineers were utilized by a citizens' committee acting for the City. In view of the problems enumerated above - costs, solids overflow, air pollution - it is not strange that alternate means of disposal were sought rather than an increase in mechanical dewatering facilities.

Our discharge of plant effluent which already contained a substantial amount of the digested solids to the ocean pointed to a similar disposal of all

digested sludge. This philosophy is not peculiar to the City of Los Angeles, since coastal cities throughout the world discharge their wastes into estuarine or marine waters. In this country, this may be observed at such places as Boston, New York, the Los Angeles County Sanitation Districts, Oakland, and Portland. The benefits of marine disposal are obvious.

The next question, that of whether to discharge sludge with the effluent or separately was then considered. While the former method is more common, separate sludge disposal has been practiced by New York City for many years, and has been more recently adopted at such installations as Boston's Nut Island Treatment Plant and the paper mill wastes at Port Gardner Bay, Washington.

Probably the most important advantage in utilizing separate disposal of sludge is that of control - the characteristics of the discharge itself can be maintained within reasonable limits. Inherent in the basic recommendations of the Citizens' Committee engineers[2,3] are the following factors:

1. A small diameter sludge line may be economically constructed to such depths at which the sludge discharge will not affect surface waters. Nor will any possible effect upon fish be of controlling significance.

2. Sludge disposal is independent from the requirements for additional treatment plant capacity. (It follows that elimination of the sludge from the effluent permits chlorination at reasonable rates in the event that future receiving water uses require disinfection.)

Further, there are advantages from a public relations point of view in that a discharge in deep water far from shore is better than one that can be seen.

To meet the basic requirements for increased capacity at the Hyperion Treatment Plant, the Citizens' Committee followed their consulting engineers, R. R. Kennedy of San Francisco and R. D. Pomeroy of Pasadena, both Members, ASCE, in recommending that the treatment be changed so that primary effluent would be discharged 5 miles offshore and digested sludge and supernatant would be discharged 7 miles offshore.

The City subsequently engaged Hyperion Engineers, Inc., a joint venture consisting of the Los Angeles engineering firms of Holmes and Narver, Inc., Koebig and Koebig; and Daniel, Mann, Johnson and Mendenhall. The various design criteria developed by Hyperion Engineers for the sludge outfall are detailed in their final report[4] and are summarized below.

Design Considerations

1. The average (design) sewage flow for the year 2,000 is 420 MGD.

2. The quantity of digested sludge and supernatant will increase from the present 1.32 MDG to 2.45 MGD in the year 2,000. A total capacity of 5.22 MGD is provided in order to allow for a reasonable dilution with final effluent.

3. In order to assure turbulent flow, a minimum velocity of 2.57 ft/sec is required. 3.55 ft/sec is provided at the design flow.

4. The design Darcy f is 0.018. While the pumping head is 73 feet, a maximum internal head of 250 feet was provided for.

5. The design life of the pipe is 100 years. Either concrete or suitably covered steel pipe is satisfactory. The final choice was 22" I.D. steel pipe

with a 3/8" wall; a 1/2" concrete inner lining; an exterior coating of coal tar, three wrappings of fiber glass and 1-1/8" of reinforced gunite; with cathodic protection. The weight of the concrete is sufficient to provide negative buoyancy with the pipe full of air as was the case during launching.

6. The required depth at the discharge end was calculated by Brooks[5] for the condition that the sludge-sea water mixture would remain submerged. Assuming that the discharge has a density of 0.9987 (primary effluent) and mixes with bottom water which is 5°F colder than the surface water and has a density of 1.02589, the mixture will have a density such that the upper surface of a thick effluent field would rise a maximum of 285 feet. The design depth was set at 300 feet (the actual depth is 320 feet) with the discharge at the head of a submarine canyon.

7. Studies of the bottom sediments were made by marine geologists of the Allan Hancock Foundation, University of Southern California[6] and of Geological Diving Consultants, Inc., San Diego[7] and by LeRoy Crandall and Associates, consulting foundation engineers, Los Angeles.[8] It was found that the bottom consisted of sand and soft silty sand, and that bedrock was not exposed along the alignment.

8. Provision for protection against scour to a depth of 10 feet by wave action along the coast is necessary.[9]

9. Analysis of the effects of a maximum bottom current of 4.5 ft/sec and a maximum temperature differential for the pipe of 30°F for the extreme conditions shows that sufficient lateral restraint will be provided by the friction of the foundation material without addition of special anchorage. As an extra precaution however, chain and block anchors were provided at intervals of 500 feet in water depths less than 150 feet.

10. Provision for mechanical cleaning of the pipe is required.

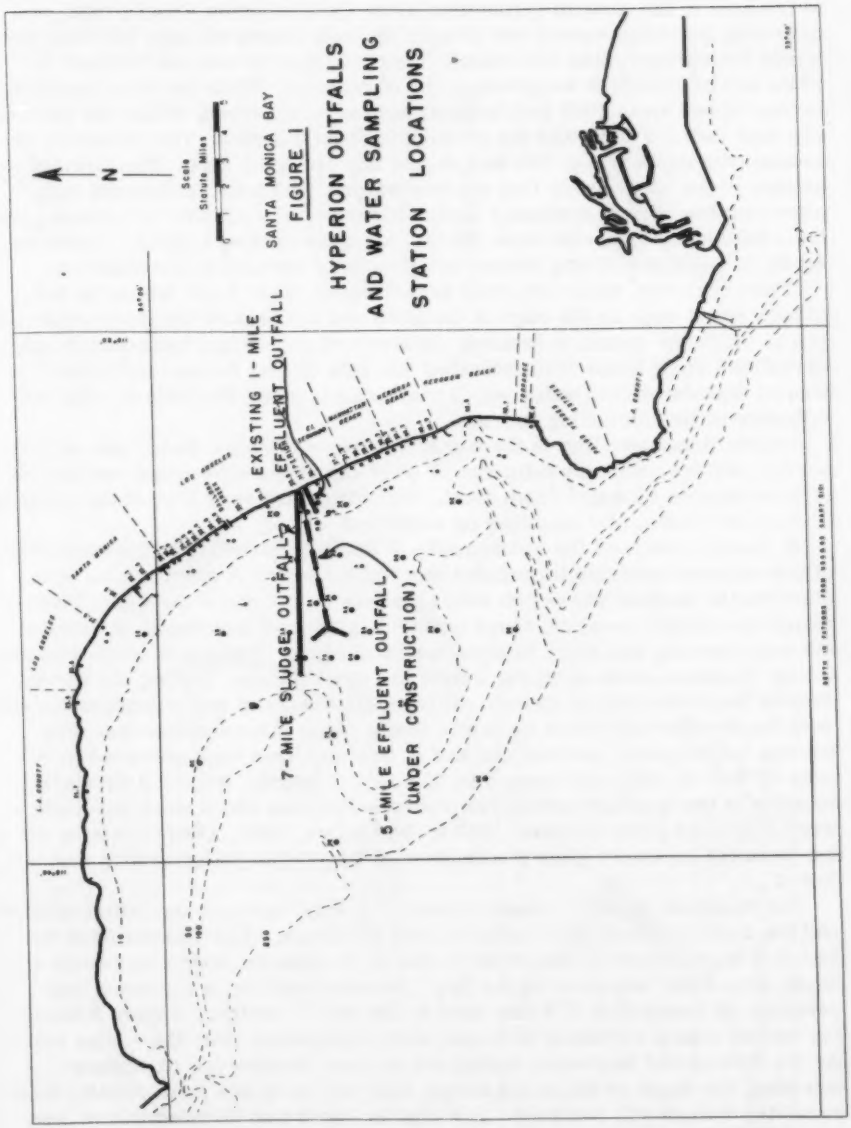
Construction

The 7-mile sludge outfall (see Figure 1) was constructed by a joint venture of the Healy-Tibbetts Construction Company of San Francisco, the De Long Corporation of New York, and the Submarine Construction Company of Port Lavaca, Texas. Narver and Graham have previously discussed in "Civil Engineering",[10] the construction program which was unique in that the 7 miles of pipe were pulled as one continuous string in 7-1/2 days. This involved making up 1,200-foot sections on a construction pier and pulling by a 500-ton winch located on a barge anchored seaward from the outfall terminus. During the pulling operation, the minimum radius of the vertical curve on the pipe as it left the ways was 3,000 feet and negative buoyancy was adjusted by having the line filled with air. The near-shore section of the pipe was buried to a depth of from 20 feet at the shoreline to zero at 5,900 feet offshore by means of a patented jetting device.

The cost of the outfall, including engineering, was $2,719,706.

Oceanography

The oceanographic background against which the operation of the outfall must be viewed includes the water currents, temperatures, and marine life regime.


HYPERION OUTFALLS
AND WATER SAMPLING
STATION LOCATIONS
FIGURE 1
SANTA MONICA BAY
EXISTING 1-MILE EFFLUENT OUTFALL
7-MILE SLUDGE OUTFALL
5-MILE EFFLUENT OUTFALL
(UNDER CONSTRUCTION)
N
Scale
Statute Miles

The currents in Santa Monica Bay may be classified as wind-drive, residual (related to the general circulation along the California Coast), tidal, and upwelling (in which waters are brought up from depths of, say, 300 feet, towards the surface along the coast). Only the wind-driven and residual currents are of sufficient magnitude to be of concern. While surface currents in excess of two knots (200 feet/minute) have been observed, 90% of the currents are less than 0.5 knot, and the average is about 0.3 knot. The velocities decrease with depth and at 300-foot depths are about 0.1 knot. The circulation pattern of the Bay is such that surface waters, which are influenced by the afternoon sea breeze, typically move shoreward in a counter-clockwise gyral from the outfall area and leave the Bay along its northern shore. Currents at depth, in addition to being slower are generally parallel to the coastline.

Tidal currents, while low, may nevertheless cause local mixing in areas of high relief such as the edge of the shelf and the head of the submarine canyon at which the outfall is located. Analysis of subsurface temperature observations made since 1955 indicates that this mixing forms large dome-shaped masses of cold water which move slowly along the bottom under the influence of the prevailing current.

Intermittent upwelling in the bay is caused by offshore movement of coastal surface waters under the influence of wind and is the subsequent replacement of these waters by water from depth. Velocities are very low, of the order of 30 feet per month, and may thus be neglected.

A characteristic of the hydrography of Santa Monica Bay is the persistence of convergence systems throughout most of the year. A convergence is the place on the surface where two water masses meet. Since the water level remains essentially constant, there is thus a downward movement of water at the convergence, and since floating material cannot continue to move with the water, it accumulates along the line of the convergence. During the warmer months large amounts of spores, oil from diatoms, and miscellaneous flotsam may be seen forming scum lines and sleeks along the convergences. Continuous convergence systems marked in this way have been observed to be over 50 feet in width and some 5 to 10 miles in length. Figure 2 shows the location of the most persistent convergence systems which were observed on weekly surveys from October, 1957 to September, 1958. Other systems exist, but were not routinely observed because of the course pattern which was followed.

The variation in water temperatures is of importance in the initial dilution and the depth at which the discharge field stratifies. This follows from the fact that temperature is the major factor in the density, which increases with depth, of normal sea water in the Bay. As noted earlier, a minimum temperature differential of $5^{\circ}F$ was used in the outfall design. Figure 3 shows the typical annual variation in temperature differential over the sludge outfall. As the differential increases during the summer months due to surface warming, the depth at which the sludge field will be at the same density as the receiving waters will increase. It should be noted that differentials of less than $5^{\circ}F$ represent the development of a thick isothermal layer due to wave mixing during winter storms; this condition persists only a few days.

While studies of the biology of Santa Monica Bay have included the plankton in the upper layers, any effects of the sludge discharge are normally limited to the attached, creeping, or crawling bottom organisms and to the bottom-dwelling fish. Changes in bottom life take place slowly and it has not been possible to observe any change during the year that the sludge outfall has been

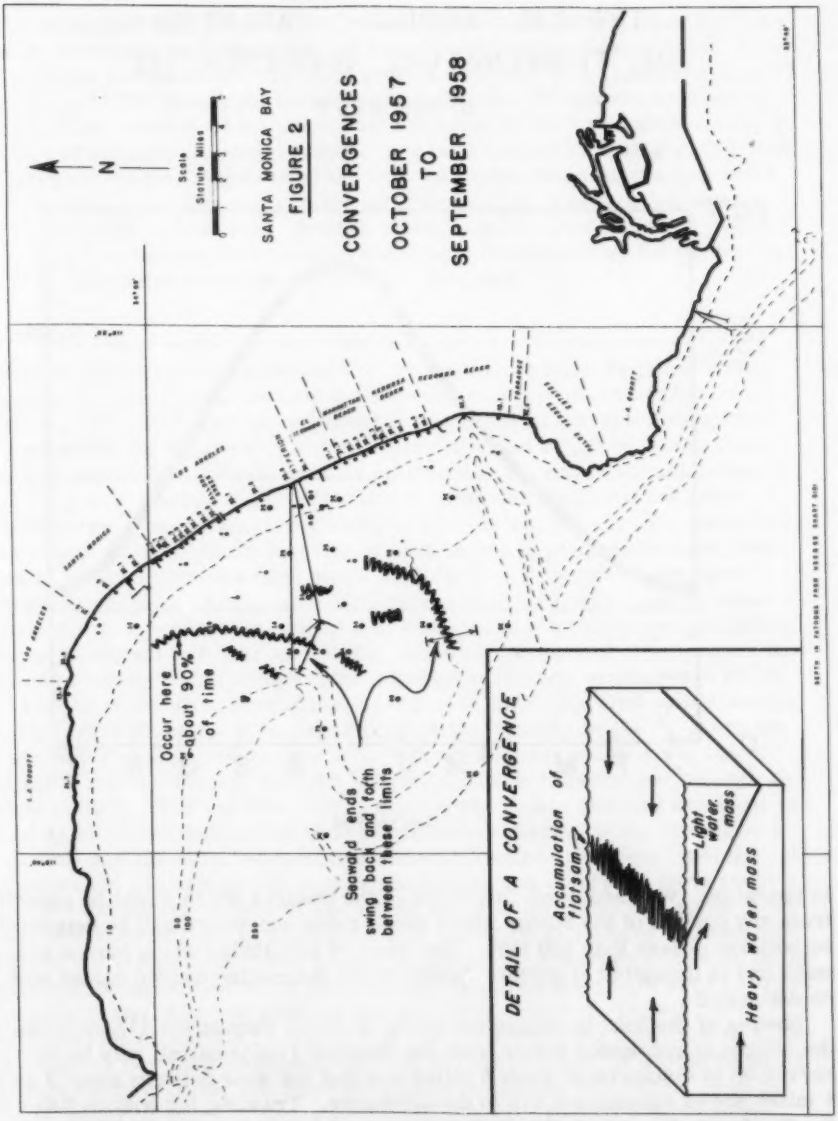
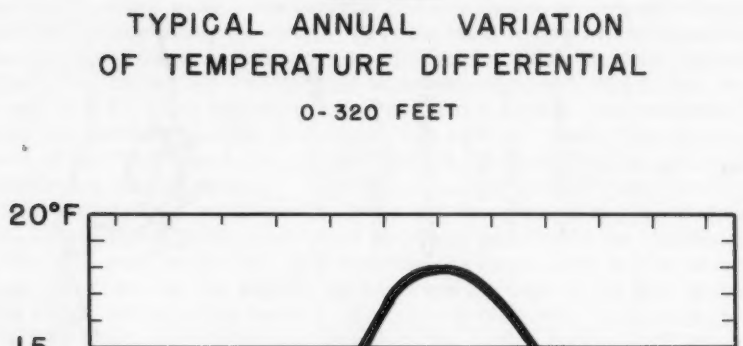

N
Scale
Statute Miles
SANTA MONICA BAY
FIGURE 2
CONVERGENCES
OCTOBER 1957
TO
SEPTEMBER 1958
Occur here about 90% of time
Seaward ends swing back and forth between these limits
DETAIL OF A CONVERGENCE
Accumulation of flotsam
Light water mass
Heavy water mass

FIGURE 3

TYPICAL ANNUAL VARIATION
OF TEMPERATURE DIFFERENTIAL
0-320 FEET



in operation. We have some indication of the changes which might be expected from any portion of the sludge which might move shoreward and be deposited on bottoms of less than 320 feet. The effect of any sludge which moves seaward and is deposited at greater depths in the submarine canyon cannot now be estimated.

Studies of the bottom organisms by the Hancock Foundation(11) show that the effects of suspended solids from the existing 1-mile outfall may be observed up to distances of about 6 miles and that the zone between about 2 and 4 miles shows enrichment due to the discharge. Trawling for bottom fish by the California Department of Fish and Game showed no significant effect of the outfall except that maximum catches were obtained over the same zone of enrichment.(12)

In order to provide a factual record of changes in bottom life which may be caused by the sludge outfall the City is engaged in a trawling program which results in collecting both bottom dwelling fish and such invertebrates as crabs

and shellfish. Trawls are made seasonally in order to evaluate natural variations and will be continued so that the actual effect of the outfall can be determined.

The estimated rate of sedimentation of sludge in the area around the outfall was developed by Brooks.(13) At the ultimate design flow, solids deposition is estimated to vary from about 0.50 lb/ft^2/yr at 1,000 feet to 0.17 lb/ft^{2}yr. at 10,000 feet from the point of discharge. Bottom cores taken in the immediate vicinity of the outfall after 3 months' operation showed only a thin film of identifiable sludge solids. The problems of sampling such a film in waters of 300-foot depths together with the bacteriological changes which affect the film over a period of time make evaluation of sludge deposition itself of doubtful importance. A much more realistic approach is to collect the bottom fish and other organisms which may be affected by the sludge, and this is being accomplished by the trawling program.

Operations

In accordance with requirements of the California State Regional Water Pollution Control Board, the City makes weekly observations of physical, chemical, biological, and bacteriological conditions at the water sampling stations shown on Figure 1. Certain information not required by the State, such as plankton and salinity data, is collected at the same time in order to more fully evaluate process control in the treatment plant and the effect of the discharge upon the receiving waters. In addition, the City has made daily determinations of coliform bacteria at surf sampling stations located along some 15 miles of the shoreline since 1946. Such a program is expensive - over $100,000/year - but it pays dividends in public relations and process control and is a reasonable part of the total cost of the City's sewage treatment and disposal into marine waters. Some of the surface observations indicate the effects of the sludge outfall operation and are summarized below.

As noted elsewhere, approximately one-half of the digested solids leaving the plant were formerly discharged through the 1-mile outfall.(1) Since the sludge outfall was placed in operation with all digested solids being discharged 7 miles offshore, only the effluent solids are discharged through the 1-mile outfall. Thus the total solids discharged 1 mile offshore has been reduced by about one-half. This change has been reflected in the appearance of the boil and the water at sampling stations located 1,000 feet from the outfall where the average Secchi disk transparency has increased from about 6 to 11 feet during the months of December through July, although some of the increased transparency is probably due to variation in plankton populations.

Since the sludge outfall was placed in operation, a marked reduction in the number of occasions on which floatable solids of sewage origin have been observed at beach sampling stations has also been obtained. During the 4-month periods of April 8 to August 8 in 1957 and 1958, the incidence of such observations has been reduced from 1.04 to 0.07 percent. It should be noted that these observations are made by trained personnel who report on presence of material which consists primarily of small, partially decomposed rubber flakes with some particulate grease balls about the size of small shot, which are on rare occasions associated with small flocs of sludge. To the layman, this material is indistinguishable from marine flotsam.

During initial operations, floatable solids have also been observed in surface waters around the sludge outfall as indicated on Figure 4. The relatively

SANTA MONICA BAY
FIGURE 4
SLUDGE OUTFALL
OPERATION
OCTOBER 1957
TO
SEPTEMBER 1958
OCCURANCE OF FLOATABLES
N
Scale
Statute Miles
NONE OBSERVED
OUTSIDE THIS LINE
NO OBSERVATIONS MADE
BEYOND THIS LINE

low incidence of such observations in the surface waters in the immediate vicinity of the outfall is due to the downstream movement of the floatables during the time, roughly estimated at from 2 to 4 hours, which is necessary for the particles to rise. The accumulation of the floatables in convergences is quite consistent. Thus we have evidence of the ability of the convergences to accumulate and retain material for sufficient periods of time to allow further alteration with the result that they cannot be found at surf stations down-current from the convergences in and around Santa Monica. Again, it must be emphasized that recognition of the small amount of floatables of sewage origin which are included within large amounts of marine debris is possible only by trained personnel.

Although the amount of floatables discharged from the treatment plant is extremely small, their presence in any amount is both undesirable from esthetic considerations and prohibited by the requirements of the Water Pollution Control Board which state, "There shall be no oily sleek or no floating or suspended solids recognizable by eye as of sewage origin. . . ." Such requirements, which necessarily involve a 100% efficiency in removal of floatables by the treatment plant, came close to implying the golden age in sewage treatment.

It was recognized in the design of the plant expansion that floatables might give cause for concern. It has been apparent for some years that changes or upsets in plant processes, even minor ones, would be reflected in the incidence of floatables at surf stations. Thus studies were made by the City and Hyperion Engineers[4] of various methods, including fine screening, mechanical disintegration, and impingement for removal of floatables. The basic problem consists of separating gas buoyed particles and true floatable material. This may be accomplished by violent agitation or washing in either a flash mixing device or a sludge impingement process (wherein jets of sludge and washing water impinge) followed by a small skimming tank. In general the efficiency of such a separation depends on the horsepower input (either mixing or impingement).

Action on final design of equipment for removal of floatables was withheld pending an analysis of the operating results of the sludge outfall so that the magnitude of the problem would be known. Further investigation is now underway, and $200,000 has been set aside for construction of adequate facilities. In the meantime, all sludge is processed in tanks originally designed as elutriation tanks. The tanks are operated so as to remove most of the flow as underdrainage and a very minor amount as overflow. The floating material (containing rubber goods, grease, hair, chaff, gas buoyed particles, etc.) is hand raked over the weirs and re-cycled to the digestion system for additional treatment.

Examinations of the water at various depths around the sludge outfall are made periodically, and include tests for bacteria, temperature, chlorinity, and ammonia-nitrogen. Such studies make it possible to evaluate the behavior of the discharge within the water itself. From 100 to 150 samples are required from various depths over an area which essentially includes the discharge field. The sampling is done over a period of about 8 hours and may, for practical purposes, be considered as simultaneous insofar as the outfall operation is concerned. Figure 5 shows the sampling stations which were occupied on a recent survey.

Figure 6 is a section taken through the approximate center of the field and shows the coliform bacteria densities. This section shows three things: that

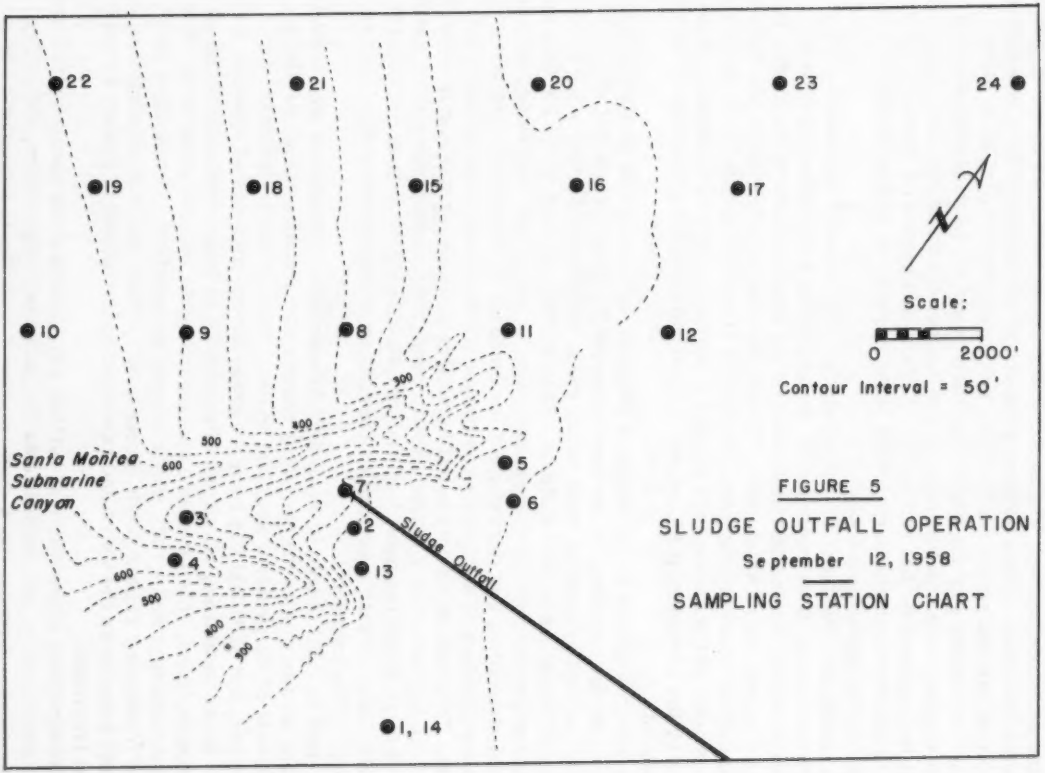


FIGURE 5

SLUDGE OUTFALL OPERATION

September 12, 1958

SAMPLING STATION CHART

SA 4

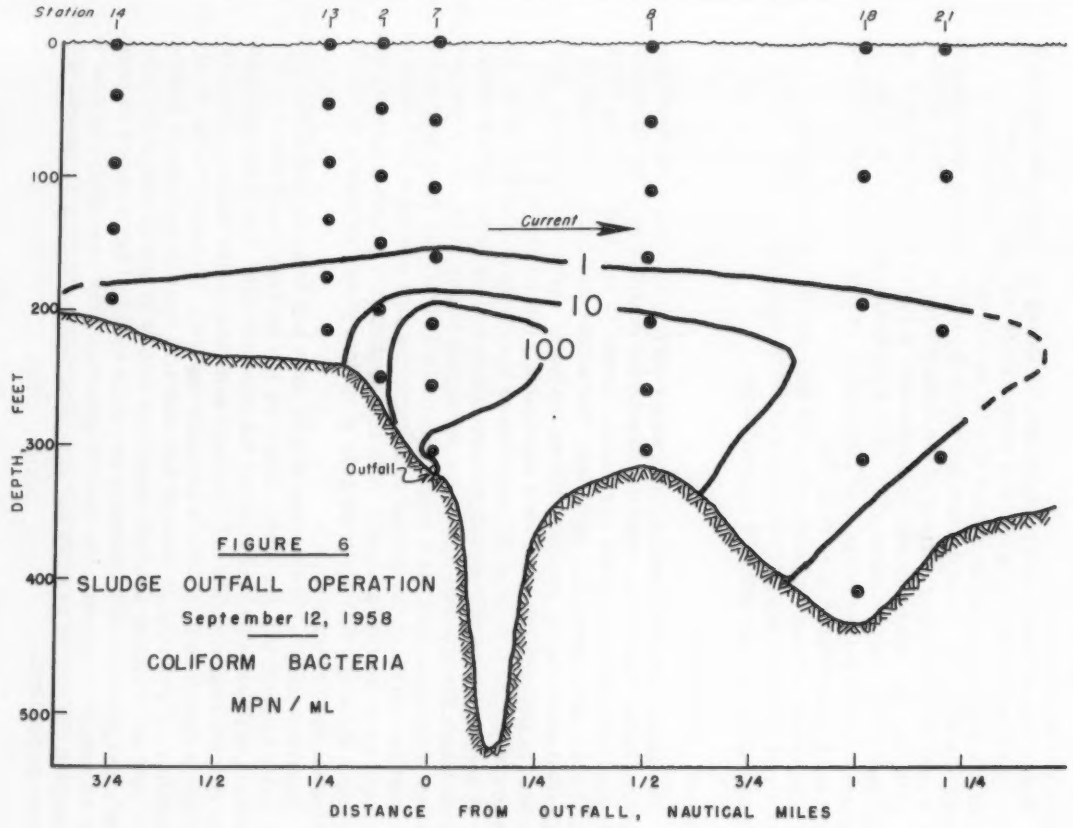


FIGURE 6

SLUDGE OUTFALL OPERATION

September 12, 1958

COLIFORM BACTERIA

MPN / ML

the main portion of the field is restricted to depths of some 200 feet; that the field extends downstream for an estimated 1-1/2 miles; and that no coliforms are found in surface waters. These results are in general conformity with earlier observations.

Water temperatures were determined by means of a bathythermograph. This provides a continuous trace of temperature vs. depth on a smoked glass slide which is then read by means of a calibrated grid. Figure 7 shows temperatures along the same section for which the coliform data were plotted. It is seen that the upper surface of the coliform field lies in water of from 56 to 57°F, and that the temperature differential between the outfall depth and the limit of the field is about 4°F. This 4° is encouraging - it is in good agreement with theory where a 5° differential was assumed, and it is less than the typical winter-time minimum.

The chlorinity and ammonia-nitrogen data are in general agreement with the above, although normal variations of these components in the receiving waters do not permit detailed comparisons.

Cathodic Protection

The line is provided with an impressed current type cathodic protection system in addition to the interior and exterior coatings in order to provide maximum protection against corrosion. Power is supplied from the Hyperion plant via a 50 ampere D.C. rectifier. The anodes are made of durichlor, a material developed to give long life in sea water service. The anode bed is located in the surf zone astride a conveniently placed storm drain outlet approximately 550 feet from the point where the sludge outfall enters the sea.

A unique feature of the cathodic protection system is the series of test leads which are attached to the pipe at various points in the ocean and brought to test stations ashore via a submarine cable. Reference rusty iron and zinc anodes are buried in the ground adjacent to the pipe and electrical leads are brought up to the test stations. With this system it is possible to quickly determine the protection given the pipe at various points by means of electrical potential measurements.

Approximately 0.180 amperes at 2.50 volts has been applied to the system in order to provide protection. This very low current requirement is due to exceptionally excellent condition of the pipe coatings. It is anticipated that the current requirements will increase somewhat in the ensuing years as the coatings deteriorate. There is adequate capacity, of course, in the 50 ampere rectifier. A potential of between 1.05 and 1.10 volts is maintained between the pipe and a copper sulphate reference cell. Current readings are taken daily and potential measurements are made weekly. Adjustments are made as necessary to maintain the desired potential. The consulting engineer who designed the system reviews our operating data and makes occasional special tests as required.

Pipeline Performance

As noted earlier, provision was made for cleaning the line at such times as experience would indicate. With one year's operation completed, analysis of the sludge pumping requirements indicates that the Darcy f of the line has increased by 23%. While the line obviously still has adequate capacity, plans are now underway for mechanical cleaning of the line. The increase in the friction factor may also be expressed as a reduction in the diameter of the

FIGURE 7

SLUDGE OUTFALL OPERATION

September 12, 1958

WATER TEMPERATURE °F

pipe amounting to about 0.4 inches. It can be speculated that this is due to the cooling of the sludge discharge by about 10°F during the flow time through the pipe and the resulting deposition of residual grease, which may remain even after complete digestion, on the pipe wall. This effect is, of course, even more pronounced with raw sludge as was found in Oakland where during the winter months, grease deposition in sludge lines has been an operating problem.(14) However, the records obtained from cleaning sludge lines within the City and elsewhere indicate that this is not considered to be of major significance in the successful operation of the sludge line.

The operating cost of the new sludge disposal method is expected to be about $1.15/ton as formerly represented by the cost of elutriation only. The power cost is less than 10% of that required for the filter and dryer operation.

SUMMARY AND CONCLUSIONS

One year's experience with a 7-mile, 21-inch diameter outfall discharging about 5 mgd of digested sludge and plant effluent into 320 feet of water in Santa Monica Bay has shown that the operation has fulfilled the expectations of the designers. The sludge field rises until it is in equilibrium with the surrounding water and then flows with the prevailing current. The water at the equilibrium level is about 4°F warmer than that on the bottom and it is indicated that, except under extreme conditions, the sludge field will be well submerged. Floatables which may be recognized by trained personnel as being of sewage origin have been observed in the Bay waters, and additional works for removal of this material are in an advanced planning stage.

ACKNOWLEDGMENTS

The authors are indebted to Messrs. W. A. Schneider, Director, Bureau of Sanitation; G. A. Parkes, W. F. Garber, J. R. Stanton, and M. E. Nelson, Engineer-Superintendent, Laboratory Director, Chemist, and Biologist, respectively, Hyperion Treatment Plant; Mr. D. L. Narver, Jr., Project Manager, and E. H. Graham, D. R. Miller and C. H. Lawrance, of Hyperion Engineers whose efforts throughout the design, construction, and operation of the sludge outfall have made this study possible.

REFERENCES

1. Bargman, R. D., J. M. Betz, and W. F. Garber, "Aeration Requirements of a High Oxygen Demand Sewage." Sewage and Industrial Wastes 29, (7): 760-790 (1957).
2. Kennedy, R. R., "Opinions and Comment on Engineering Features of Proposed Solutions of the Sewerage Problem of the City of Los Angeles for Citizens' Committee on Sewerage Problem, George B. Gose, Chairman." (September 1954).

3. Pomeroy, Richard, "Opinions and Comment on Engineering Features of Proposed Solutions of the Sewerage Problem of the City of Los Angeles for Citizens' Committee on Sewerage Problem, George B. Gose, Chairman." (September 1954).

4. Hyperion Engineers, "Ocean Outfall Design." Hyperion Engineers, 828 So. Figueroa St., Los Angeles. (1957).

5. Brooks, N. H., "Depth of Discharge for Hyperion Sludge Outfall," Memorandum report to Hyperion Engineers (November 1955). See Ref. (4), pp 4-22 to 4-25.

6. Terry, R. D., S. A. Keesling, and E. Uchupi, "Submarine Geology of Santa Monica Bay, California," Allan Hancock Foundation, University of Southern California (1956) See Ref. (4), Sec. 7.

7. Geological Diving Consultants, "Reports of Underwater Survey Along Proposed Hyperion Sludge Outfall," Report to Hyperion Engineers (January 1956). See Ref. (4), pp 7-12 to 7-16.

8. Crandall, L. L., "Report of Offshore Explorations, Proposed Sludge Line Hyperion Outfall for the City of Los Angeles," Report to Hyperion Engineers (February 1956). See Ref. (4), pp 7-14.

9. Tibby, R. B., "Changes in Topography of the Beach and Foreshore in the Region of the Hyperion Sewage Treatment Plant," Report to Hyperion Engineers (December 1955). See Ref. (4), pp. 7-20 and 7-30.

10. Narver, D. L. Jr., and E. H. Graham, Jr. "Two Long Ocean Outfalls Constructed." Civil Engineering 28 (1): 6-11. (1958).

11. Hartman, Olga, "Contributions to a Biological Survey of Santa Monica Bay, California," Allan Hancock Foundation, University of Southern California (1956).

12. Horrer, P. L., et al, "Sewage in Santa Monica Bay, A Critical Review of of the Oceanographic Studies." Marine Advisors, P. O. Box 1001, La Jolla, California (1956).

13. Brooks, N. H., "Predictions of Sedimentation and the Dilution of Digested Sludge in the Santa Monica Bay," Report to Hyperion Engineers (August 1956). See Ref. (4) pp. 4-26 and 4-31.

14. Ross, Elmer, "Raw Sludge Pumping Experiences at East Bay Municipal Utilities District Plant." Paper presented at 30th Annual Conference, CSIWA, April 1958.

Se
from
rived
velop
and S
are a
varia
comr

A
proc
air b
the c
to tr
negle
If
since
fer c

Equa

Note
a
p
o

1. A

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

ABSORPTION OF OXYGEN FROM AIR BUBBLES IN WATER

W. Wesley Eckenfelder Jr.[1] M. ASCE

ABSTRACT

Several correlations have been developed to define the absorption of oxygen from gas bubbles in water. In most cases, these correlations have been derived from bubble cap plates and other low head devices. This paper develops relationships between the liquid film coefficient, K_L and the Reynolds and Schmidt Numbers at liquid submergence depths up to 15 ft. Correlations are also developed relating the overall coefficient, K_La, to pertinent process variables. The correlations developed from laboratory data are extended to commercial diffusion devices.

Aeration is employed for the transfer of oxygen in biological oxidation processes. This oxygen transfer is usually accomplished by diffusion from air bubbles discharged from submerged orifices. It has been shown that in the case of slightly soluble gases such as oxygen, the controlling resistance to transfer occurs in the liquid film and the gas film resistance can be neglected.(1)

If the interfacial concentration, C_{ai}, is assumed as saturation C_s, and since the liquid film offers the controlling resistance, the rate of mass transfer can be expressed:

$$N_A = K_L (C_s - C_L) \tag{1}$$

Equation (1) can be re-expressed in concentration units:

$$N = \frac{dw}{A dt} \quad \text{and}$$

$$\frac{1}{V}\frac{dw}{A dt} = \frac{dc}{dt} = K_L \frac{A}{V}(C_s - C_L) \tag{2}$$

Note: Discussion open until December 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2090 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. SA 4, July, 1959.

1. Associate Prof. of Civ. Eng., Manhattan College, New York, N. Y.

It is apparent from Equation (2) that the rate of oxygen transfer will depend upon the magnitude of the liquid film coefficient K_L, and the ratio of interfacial area to liquid volume A/V.

The liquid film coefficient has been related to the diffusivity and to the thickness of a laminar layer or film through which diffusion must occur.(2) The thickness of this layer is related to fluid turbulence.

Higbie(3) and later Dankwertz(4) related the liquid film coefficient to the square root of the product of the diffusivity and the rate at which layers of water molecules adjacent to the air bubbles are replaced by layers from the body of the fluid. This rate must necessarily be related to the velocity of the air bubble relative to the water. Similar relationships have been employed by Pasveer(7) to describe the bubble aeration process.

For the transfer of oxygen from air bubbles in a column of water, the interfacial area - volume ratio will depend on the total area of the bubbles passing through the water and on the exposed surface at the top of the column.

Bubble Aeration

In diffused aeration, air bubbles are formed at an orifice, from which they break off and rise through the liquid, finally bursting at the liquid surface. Oxygen transfer occurs during each phase of the bubble's life. As the bubble emerges from the orifice the absorption rate is very high. The air water interface is continually replenished during bubble formation resulting in a high surface renewal rate. When the bubble reaches its terminal velocity the transfer rate is constant as it rises through the liquid. The effective film thickness and the rate of surface renewal will vary with the bubble velocity and hence the mass transfer will be related to the velocity of the bubble, v_b, relative to the liquid. In aeration tanks where the liquid is in motion, the transfer process is complicated by eddy currents which result in irregular bubble movement.

The water surface will be continually renewed by the air bubbles bursting as they rise to the surface and shed an oxygen saturated film into the surface layers. Velocity gradients will also be induced at the surface through fluid turbulence generated by the rising bubbles resulting in additional surface reaeration. To account for the three transfer phases Equation (1) can be modified:

$$N = k_{L(f)} A_f (C_{sb} - C_b) + k_{L(b)} A_b (Cs_M - C_M) + k_{L(s)} A_S (C^* - C_n) =$$

$$K_L A (C_s - C_L) \qquad (3)$$

The liquid film coefficient during bubble formation and release has been reported to be higher than that created by the rising bubbles. It may therefore be expected that the overall liquid film coefficient, K_L, will vary inversely with liquid depth.

Various attempts have been made to independently evaluate $k_{L(f)}$, $k_{L(b)}$, and $k_{L(s)}$. The coefficient for rising bubbles varies over the surface of the bubble. Adeney and Becker(5) showed that air bubbles rising at a velocity of 9 cm/sec. exhibited a liquid film coefficient of 32 cm/hr at the side surface and 230 cm/hr at the tip where higher surface renewal rates were caused by the surface drag. An average coefficient for rising oxygen bubbles 0.03 cm.

diameter of 45 cm/hr was determined by Pattle.[6] Indirect calculations of the data of Pasveer[7] showed values for $k_{L(b)}$ to range from 43 - 83 cm/hr for a range in air bubble diameter of 0.076 - 0.118 cm.

The surface film coefficient, $k_{L(s)}$ has been expressed in terms of an exponential function of the liquid velocity at the surface.[8] For surface velocities varying from 2.3 - 3.5 ft/sec reported by King,[17] the surface film coefficients computed from the formulas of Streeter could be expected to vary from 40 - 80 cm/hr. Recent studies on an air sparger at 8 ft. submergence and air rates of 8 - 15 scfm have shown the velocity gradient to vary from 4 - 6/sec two feet from the air source. Employing the relationships of O'Connor and Dobbins[16] the surface film coefficient would be of the order 30 - 40 cm/hr. The coefficient would be considerably greater directly above the air source. Values of $k_{L(s)}$ as high as 250 cm/hr have been reported for a highly turbulent aeration tank surface.[9] While very little data is available as to the film coefficient during bubble formation, Kountz[10] has indicated that as much as 30% of the total transfer occurs during bubble formation.

Since it is not possible to independently evaluate the individual film coefficients, an overall coefficient, K_L, is usually employed which can be related to the depth of the aeration column and to the rising velocity of the bubbles.

Bubble Velocity and Size

The velocity and shape characteristics of air bubbles in water can be related to a modified Reynolds Number.[11] At Re less than approximately 300, the bubbles are spherical and act as rigid spheres. The bubble rise if rectilinear or helical. Over a Re range of 300 - 4000 the bubbles assume an ellipsoidal shape and rise with a rectilinear, rocking motion. The bubbles form spherical caps at Re greater than 4000.

The rising velocity of the bubbles is increased at high air flows due to the proximity of other bubbles and resulting disturbances of the bubble wakes.

The size of air bubbles released by diffused aeration devices is related to both the orifice diameter and the air rate. At low air rates the bubble volume is directly proportional to the orifice diameter and the surface tension and inversely proportional to the liquid density. The bubble size produced will result from a balance of the buoyant force separating the bubble from the orifice and the shearing force necessary to break the surface tension across the orifice.[12] At high air rates the bubble diameter increases as a function of the gas flow rate. Over the range of air rates normally encountered in aeration practice the mean diameter of bubble produced is an exponential function of the gas rate

$$d_b \sim G_s^{\,n} \tag{4}$$

Data from four diffusers employed by Pasveer[7] showed the exponent n to vary from 0.10 to 0.44.

The liquid film coefficient will increase with increasing bubble size. This increase will approximately parallel the variation in terminal bubble velocity with bubble size.

Correlations of Mass Transfer Data

Several efforts have been made to correlate mass transfer data from bubble aeration systems. Hammerton and Gamer[13] showed that the Frossling

equation could be employed to correlate oxygen transfer data when the bubbles acted as rigid spheres and before bubble circulation started (< 0.02 cm diameter). This correlation was also applied to those cases where the presence of contaminants prevented bubble circulation. Over a bubble diameter range of 0.3 - 0.8 cm, Higbie's formula was found to give a reasonable correlation. The time of surface renewal was estimated to be that required for the bubble to rise one diameter. Camp[14] developed a similar relationship from the data of Ippen and Carver[12] which employed a modification of the Dankwertz equation:

$$K_L = \sqrt{m} \sqrt{D_L \, V_b/d_b} \qquad (5)$$

Effects due to variations in submergence depth were not considered in the above correlations.

Quigley, Johnson and Harris[15] developed a relationship for large bubbles discharged from submerged orifices on performated gas absorption plates at low submergence depths:

$$K_L = C \sqrt{d_b} \cdot {}^{1}/_{S_c}{}^{2/3} \qquad (6)$$

The liquid film coefficient for oxygen transfer from a moving surface under turbulent conditions has been shown by O'Connor and Dobbins to be:

$$K_L = \frac{D_L V_L}{h} \qquad (7)$$

None of the aforementioned equations have correlated oxygen transfer data over a wide range of submergence depth and bubble characteristics. It has been previously shown that the overall transfer coefficient, K_L, increases with decreasing depth due to the three phases of the transfer process. Transfer coefficients developed for various depths and bubble sizes have been correlated to the Sherwood Number and the Reynolds Number as shown in Figure 1. These data were reported from aeration in a laboratory column by Pasveer[7] using several types of air diffusion devices.

An emperical correlation between the overall liquid film coefficient, K_L, and submergence depth for air bubbles rising through a column of water was obtained from a cross-plot of Figure 1. Liquid film coefficients over a range of submergence depths of 0.6 ft. to 12 ft. and a range of bubble diameter of 0.05 - 0.2 cm are shown in Figure 2. Data reported by Ippen and Carver[12] for various submergence depths is also included in this figure. At constant Reynolds Number the correlation is:

$$\frac{K_L d_b}{D_L} = {}^{C}/_{h}{}^{1/3} \qquad (8)$$

A linear relationship between the film coefficient and submergence depth on log-log paper has also been reported by Shulman and Molstad.[20] A general correlation relating the Sherwood Number, the Reynolds Number, the Schmidt Number and submergence depth is shown in Figure 3. From the data available it was not possible to directly evaluate the effect of the Schmidt

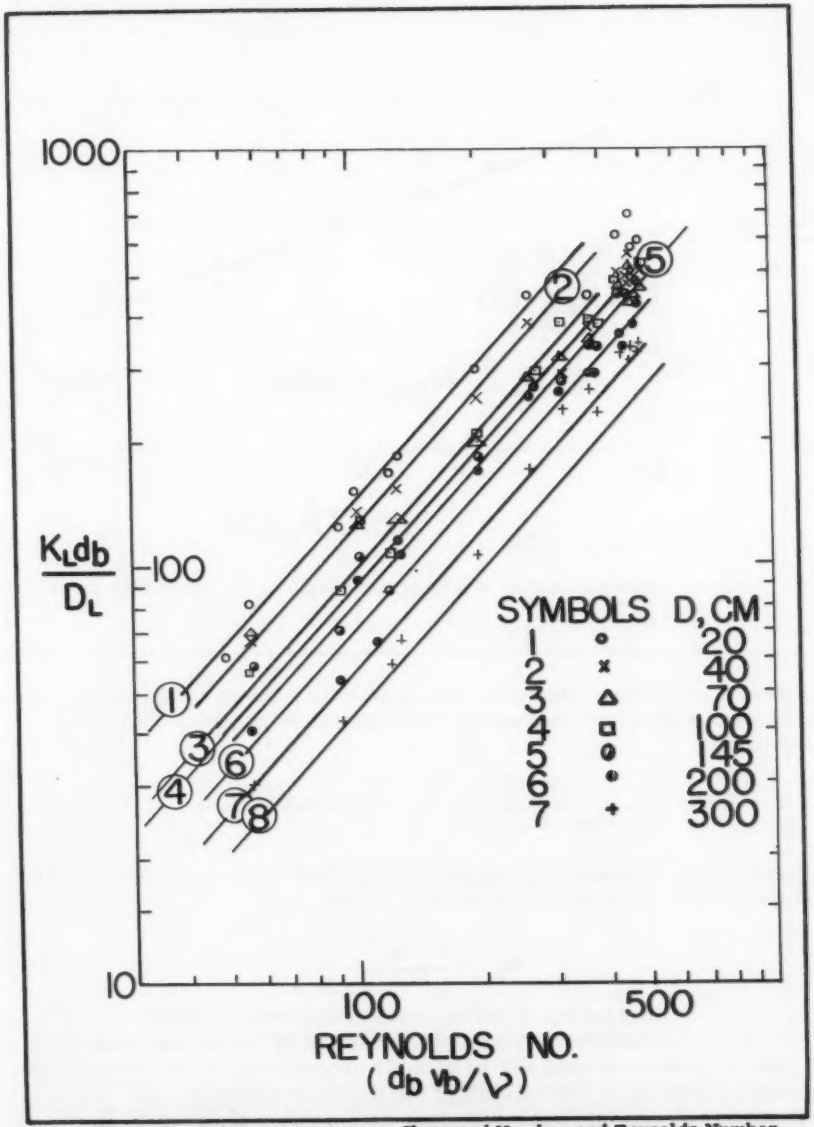


Figure 1 - Relationship Between Sherwood Number and Reynolds Number at Various Submergence Depths

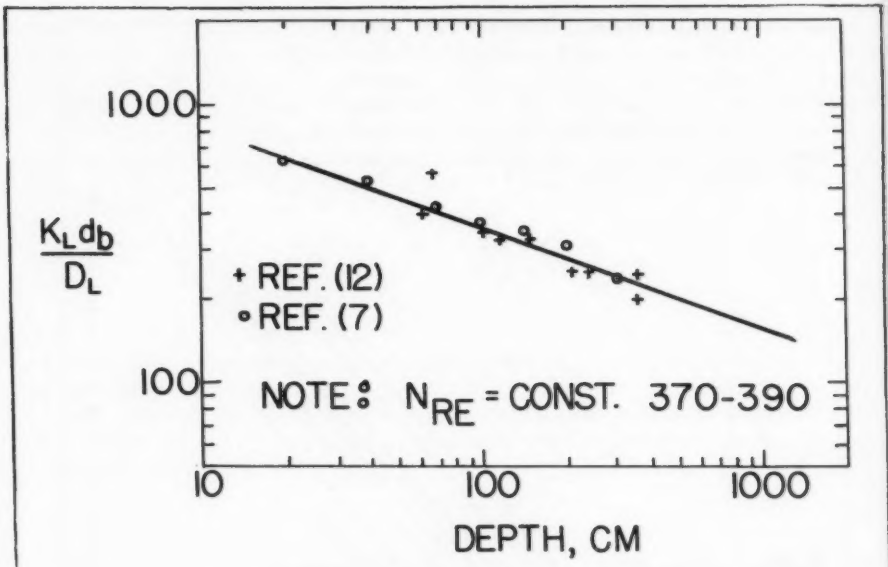


Figure 2 - Effect of Submergence Depth on the Liquid Film Coefficient

Number on the transfer process. An exponent of 0.5 was computed from the equations of Higbie and Dankwertz. The general relationship obtained for these data is:

$$\frac{K_L d_b}{D_L} \cdot h^{1/3} = C\,(Re)(Sc)^{1/2} \qquad (9)$$

Rearranging Equation 9 shows the overall liquid film coefficient for air bubbles rising through a column of water to be:

$$K_L = \frac{C\,V_b}{h^{1/3}} \cdot \frac{1}{Sc^{1/2}} \qquad (10)$$

Considered in light of the relationships developed by Higbie and Dankwertz the rate of surface renewal will be directly proportional to the square of the velocity and inversely proportional to the liquid viscosity.

Equations (8) and (10) were developed over a range of Reynolds Number of 50 to 500 and a range of depth of 0.6 ft - 12 ft. For Reynolds Numbers in excess of 5000 Quigley, Johnson and Harris[15] showed the surface renewal rate to be inversely proportional to the bubble diameter and the fluid viscosity.

Overall Mass Transfer Coefficients

When considering the performance of commercial aeration equipment it is convenient to consider the aeration process in terms of overall mass transfer

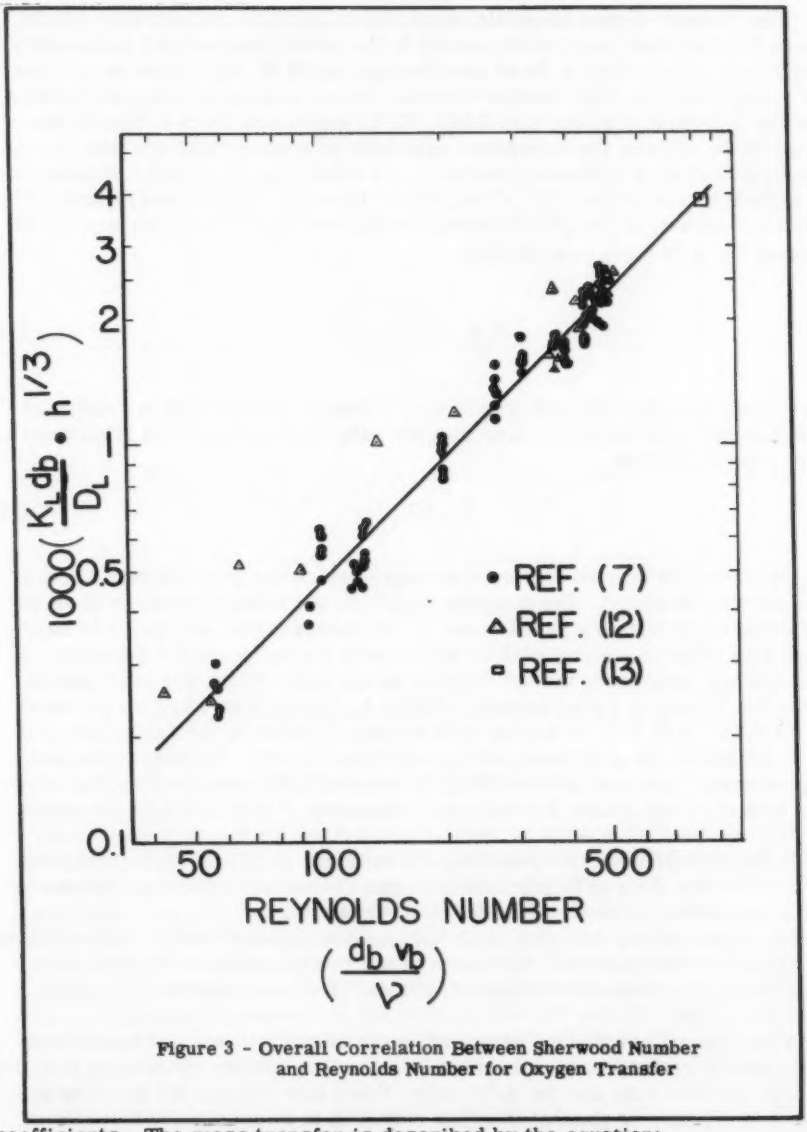


Figure 3 - Overall Correlation Between Sherwood Number and Reynolds Number for Oxygen Transfer

coefficients. The mass transfer is described by the equation:

$$N/V = K_L \frac{A}{V} (C_s - C_L) = K_L a (C_s - C_L)$$

In bubble aeration processes A/V is equal to:

$$\frac{6 G_s h}{d_b v_b V} + C \left\langle \frac{1}{h} \right\rangle \qquad (11)$$

The first term expresses the area-volume relationship for the bubble surface and the second for the tank surface.

For the deep depths normally employed in aeration practice (10 - 15 ft) the term 1/h becomes small with respect to the bubble surface and can usually be neglected. For example, in an aeration tank of 15 ft. depth with an air flow of 20 scfm/1000 cu ft and a bubble diameter of 0.1 inches, A/V for the bubbles will be 1.8 and for the surface 0.067. (1/h) would represent a smooth surface, while actually the interfacial area will be considerably greater, due to the high degree of surface turbulence. To compensate for this a constant C is included in Equation (11). C is greater than 1.0. Equations (10) and (11) can be combined to define the overall coefficient K_La where the surface effect on the A/V ratio is neglected.

$$K_La = \frac{C'h^{2/3}G_s}{Vd_bS_C^{1/2}} \tag{12}$$

Combining Equation (4) with Equation (12) where the exponent n relates to both the variation in bubble size with air rate and turbulence as influenced by tank geometry gives:

$$K_La \cdot V = C'' G_s^{(1-n)} h^{2/3} \tag{13}$$

Equation (13) may be employed to characterize the performance of aeration devices in water. The exponent of 2/3 on the submergence depth as determined from the aeration of water in tall columns has been found to vary from this value in commercial aeration tanks depending on the geometry of the tank and location of the air diffuser in the tank. Plate diffusers placed along the bottom of a rectangular aeration tank were found to give an exponent of 0.71 - 0.77.[17] A four-nozzle sparger located on the centerline of a 14 ft. diameter aeration tank gave an exponent of 0.78. Diffuser tubes and impingement type units placed along the sidewall of a wide rectangular aeration tank aerating sulfite solution gave exponents of 0.45 and 0.65 respectively.[18]

In commercial aeration practice, the exponent (1-n) in Equation (13) will reflect the variation in bubble size with gas rate and the effect of tank turbulence and geometry on the bubble size distribution.

For small orifice diffusion units the exponent is less than 1.0 indicating an increasing bubble size over the range of air flow normally employed. For a wide range of commercial diffusion devices, (1-n) has been found to vary from 0.8 - 1.0.

In the case of nozzle type spargers, increasing air rates and tank turbulence tend to redivide larger bubbles into smaller bubbles increasing both the surface renewal rate and the A/V ratio. When this occurs, the gas rate exponent (1-n), may be greater than 1.0 resulting in an increasing transfer efficiency with increasing gas rate. This phenomenon is related to the tank geometry and the location of the diffuser unit.

This was confirmed in studies conducted by the author, which showed a range in gas flow exponent of 0.86 - 1.35 for a particular sparger unit depending on the geometry of the aeration tank and the location of the sparger unit.

Typical data for a sparger aeration unit is correlated according to Equation (13) and Figure (4).

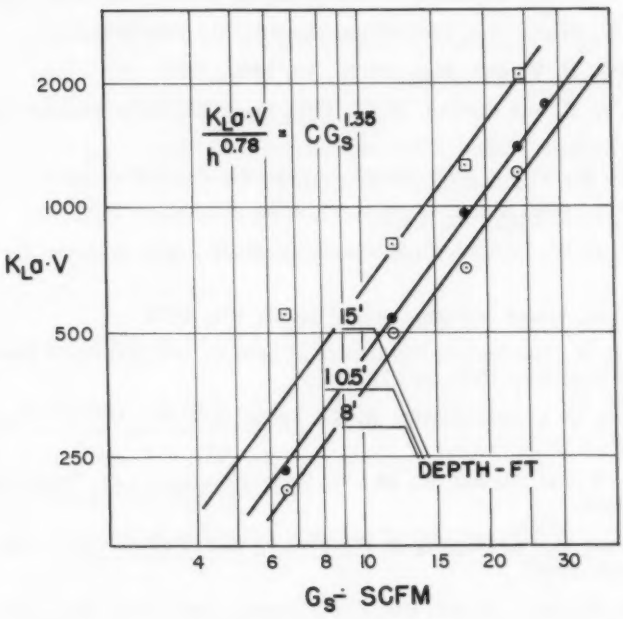


Figure 4
Oxygen Transfer Characteristics of a Diffused Aeration Device

SUMMARY AND CONCLUSIONS

The liquid film coefficient for the transfer of oxygen from air bubbles in water has been found to be directly proportional to the bubble velocity relative to the liquid and inversely proportional to the kinematic viscosity. The correlation has covered a range of bubble diameters of 0.05 - 0.2 cm and a range of Reynolds Numbers of 50 - 500.

The correlations have been extended to define the oxygen transfer characteristics of commercial air diffusion devices in terms of overall coefficients. The constants and exponents in the correlation will vary depending on the geometry of the aeration tank and on the location of the air diffusion device.

ACKNOWLEDGMENT

This study was supported by research grant RG - 4694, National Institute of Health, U. S. Public Health Service.

REFERENCES

1. Treybal, R. E. "Mass Transfer Operations," McGraw Hill Book Co., New York, N. Y. (1955).

2. Lewis. W. K. and Whitman, W. C., Ind. Eng. Chem., 16, 1215, 1924

3. Higbie, J., Trans. Am. Inst. Chem. Engrs., 31, 365, 1935.

4. Dankwertz, P. V., Ind. Eng. Chem., 43, 1460, 1951

5. Adeney, W. E. and Becker, H. G., Phil. Mag., 38, 317, 1919 and 39, 385, 1920.

6. Pattle, R. E., Trans. Inst. Chem. Engrs., 28, 27, 1950.

7. Pasveer, I., Sewage Ind. Wastes, 27, 1130, 1955.

8. Streeter, H. W., Wright, C. T. and Kehr, R. W., Sew. Wks. Jour., 8, 282, 1936.

9. Holroyd, A., Water and San. Eng., (Br.) 3, 301, 1952.

10. Kountz, R. R. "Biological Treatment of Sewage and Industrial Wastes," Reinhold Pub. Co., 1956, pp 212.

11. Haberman, W. L. and Morton, R. K., Trans. Am. Soc. of Civil Engrs., 121, 227, 1956.

12. Ippen, A. T. and Carver, E., M.I.T., Hydrodynamics Lab. Tech., Rept, No. 14, 1955.

13. Hammerton, D. and Gamer, F. H., Trans., Inst. Chem. Engrs. (Br.) 32, 1954 Supplement.

14. Camp, T. R., Proc. Amer. Soc. Civil Engrs., Jour. San. Eng. Div. 1227-9, April 1957.

15. Quigley, C. J., Johnson, A. I. and Harris, B. L., Chem., Eng. Prog., Symposium Series, 51, 16, 1955.

16. O'Connor, D. J. and Dobbins, W. E., Trans., Am. Soc. of Civil Engrs., 123, 641, 1958.

17. King., H. R. Sewage Ind. Wastes, 27, 894, 1955.

18. Dreier, D. E. "Biological Treatment of Sewage and Industrial Wastes" Reinhold Pub. Co., 1956, pp 222.

19. Cappock, P. D. and Micklejohn, G. T., Trans Inst. Chem. Engrs., (br) 29, 75, 1951.

20. Shulman, H. L. and Molstad, M. C. Ind. Eng. Chem., 42, 1058, 1950.

Nomenclature

A - interfacial area for transfer

a - ratio of interfacial area to liquid volume

C, C', C''. . . constants

C_L - dissolved oxygen concentration in the liquid

C_s - saturation of oxygen in water or waste at the mean depth and average oxygen concentration in the gas phase.

c, c', c''. . . exponents

D_L - diffusivity of oxygen in water

d_b - mean diameter of air bubble

G_s - air flow

h - tank liquid depth

$k_{L(f)}$, $k_{L(b)}$, $k_{L(s)}$ - liquid film coefficient during bubble formation, bubble rise, and surface aeration respectively.

K_L - overall liquid film coefficient

K_La - overall oxygen transfer coefficient

n - gas rate exponent

Re - Reynolds Number $\left(\frac{d_b V_b}{\gamma}\right)$

S_d - Schmidt Number - $\left(\frac{\gamma}{D_L}\right)$

V - volume of liquid under aeration

V_L - liquid velocity

v_b - velocity of air bubble relative to tank liquid

Journal of the

SANITARY ENGINEERING DIVISION

Proceedings of the American Society of Civil Engineers

CONTENTS

DISCUSSION

Page

Advances in Secondary Processes of Sewage Treatment in the Period October 1, 1954 - June 1, 1957. Progress Report of the Subcommittee on Secondary Treatment of the Committee on Sewage Treatment. (Proc. Paper 1612, April, 1958. Prior discussion: 1855. Discussion closed.) ..... --*

Sewage Treatment By Lagoons, by The Sanitary Engineering Research Committee, Sewage Treatment Section. (Proc. Paper 1678, June, 1958. Prior discussion: 1855; 1921. Discussion closed.)
by Committee (closure) 103

Controlled Submergence of Pittsburgh's Deep Sewage, by J. F. Laboon. (Proc. Paper 1717, July, 1958. Prior discussion: 1921. Discussion closed.)
by J. F. Laboon (closure) 105

Forests and Water Yield, by Nadavia Bethlahmy. (Proc. Paper 1848, November, 1958. Prior discussion: 1921. Discussion closed.)
by Nadavia Bethlahmy (closure) 107

Municipal Composting in the United Kingdom, by C. A. Gordon. (Proc. Paper 1852, November, 1958. Prior discussion: 2044. Discussion closed.)
by C. A. Gordon (closure) 109

(Over)

Note: Paper 2098 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 85, SA 4, July, 1959.

* There will be no closure.

Page

Treatment of Liquid Radioactive Wastes, by C. Straub. (Proc. Paper 1930, January, 1959. Prior discussion: none. Discussion closed.)
by P. Dejonghe 111
by Pierre Cohen 111

Hydrology of Urban Runoff, by A. L. Tholin and Clint J. Keifer. (Proc. Paper 1984, March, 1959. Prior discussion: none. Discussion open until August 1, 1959.
by L. Tholin and Clint J. Keifer (corrections) 113

SEWAGE TREATMENT BY LAGOONS[a]

Closure by the Committee

THE COMMITTEE.—Interest in lagoons as a method of sewage treatment has been motivated largely by economic considerations. In general it appears that acceptance and use of the sewage lagoon or so-called stabilization pond has increased rapidly during the past few years.[1] Accurate economic evaluation of this method of sewage treatment is not possible at this time owing to a lack of reliable cost data. However, comparison of available cost data indicates that the use of lagoons in place of conventional sewage treatment may result in an annual savings ranging as high as $10.00 to $30.00 per capita for population groups of 2000 or less people.

Obviously the economy of the lagoon process is determined in large measure by the hydraulic and the biological loadings which can be tolerated. Most design criteria in use at the present time appear to be conservative. Herbert Moore's description of a small lagoon loaded at the rate of 750 people per acre is interesting. Apparently the primary criterion of successful operation in this instance was the absence of odors. It would be of interest to know what was being accomplished in terms of reduction in BOD and coliform bacteria.

The writer has heard of several apparently successful raw sewage lagoons operating under loadings in the range of 500 to 1000 people per acre. In most instances actual performance data are lacking. In fact, adequate data presently are not available to allow reliable prediction of treatment costs or to permit rational description of safe or optimum loading rates. There is need for further field investigations such as those carried out by the U. S. Public Health Service and for continued research and development such as the excellent work now being carried out at several universities. It is hoped that future field investigations and facilities inventories will be concerned with operation and maintenance costs.

---

a. Proc. Paper 1678, June 1958 by the Sanitary Engineering Research Committee, Sewage Treatment Section.

1. Thoman, John R., and Jenkins, Kenneth H., Statistical Summary of Sewage Works in the United States. Public Health Service Publication No. 609 (1958).

CONTROLLED SUBMERGENCE OF PITTSBURGH'S DEEP SEWAGE[a]

Closure by J. F. Laboon

J. F. LABOON,[1] F. ASCE.—The first sentence in the fourth paragraph of the discussion by Messrs. Cobb and Burdoin is as follows: "The selection of sewer sizes to maintain minimum velocities of approximately one foot per second at minimum flow when flowing full resulted in a very deep station of unusual design." Although this was a contributory factor it was a minor one. The principal factor in determination of the depth of the wet well was the decision to construct 30.5 miles of the intercepting sewer in tunnel because of the extremely congested areas and practical impossibility of constructing it in open-cut trench. The depth of the tunnel was then determined by the depth of the rock at certain critical locations and the depth of the pumping station was in turn determined by the depth of the tunnel. Any further increase in depth of pumping station because of selection of sewer sizes to maintain the minimum velocity of approximately one foot per second at minimum flow when flowing full was only a small percentage of the total depth.

One other statement which is believed to be not quite correct is the second sentence in the next to last paragraph; namely, "Special investigations were carried out at the Carnegie Institute of Technology which resulted in the development of a new design of drop inlet which would function effectively with minimum air entrainment throughout the range of interceptor water levels to be encountered in operation." The method used was not selected because of a tendency to take in a minimum of air but because it produced the smoothest flow and had no tendency to produce a vacuum in the downshaft with resultant pulsating flow and tendency to cavitation. As a matter of fact, the intake of air will be considerable under certain conditions but it was felt that it could be more readily provided for in design than the unsatisfactory conditions of other types of flow.

a. Proc. Paper 1717, July, 1958 by J. F. Laboon.

1. Executive Director and Chf. Engr., Allegheny County Authority, Pittsburgh, Pa.

FORESTS AND WATER YIELD[a]

Closure by Nedavia Bethlahmy

NEDAVIA BETHLAHMY.[1]—Mr. Stevens is entirely correct in stating that the U. S. Forest Service is "one of our most valuable assets." He is also correct in stating that forests minimize soil erosion and are a source of timber supplies. But the weight of evidence does not substantiate his belief that forests have nothing to do with either the forest environment or with the disposition of precipitation. In the past fifty years the field of forest influences has outgrown its swaddling clothes, assumed the stature of a science, and has even given birth to a new science: the field of Watershed Management. In the process of growth, a myriad of facts have been uncovered, and many of the beliefs of yesteryear simply will not withstand the mass of accumulated evidence.

Public controversies tend to elicit extreme arguments by both antagonists and protagonists. Such was the case before the turn of the century when the question of public forests was being discussed. But the heat of public debate has long since abated, and the problem of forest influences has been properly relegated to research laboratories and the cold, searching, detached scrutiny of scientists.

Mr. Stevens is entitled to a detailed reply. However, this has already been done so well by others that it would be presumptuous of the author even to attempt the task. Two excellent books have been published in the past decade, and they should supply food for thought to any engineer who is concerned with water supplies or is interested in the problem of forest influences. In 1953, E. A. Colman(1) published a very fine book appraising the role of vegetation management in relation to water supply, flood control, and soil erosion. In 1948, Joseph Kittredge(2) wrote a college text covering the field of forest influences, or "the effects of woody vegetation on climate, water and soil." A perusal of these books should convince any engineer that forests do in fact exert a profound influence on their environment and that not by any stretch of the imagination can they be viewed solely as "a perpetual source of timber supplies."

REFERENCES

1. E. A. Colman, Vegetation and Watershed Management. Ronald Press Co., N. Y. 412 pp., illus.
2. Joseph Kittredge. Forest Influences. McGraw Hill Book Co., Inc., N. Y. 394 pp., illus.

---

a. Proc. Paper 1848, November 1958, by Nedavia Bethlahmy.
1. Research Scientist, U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Ore.

C
point
T
this
done
atte
N
Edin
been
Crai
M
syst
the
bere
sew
Jers
burg
rapi
be

a.
1.

MUNICIPAL COMPOSTING IN THE UNITED KINGDOM[a]

Closure by C. A. Gordon

C. A. GORDON,[1] A.M. ASCE.—Mr. Perkins has raised two interesting points in connection with composting in the United Kingdom.

The pulverising plant at Southwark in London was not mentioned because this plant was simply a separation and pulverising plant; no composting was done. Mr. Perkins is correct in saying that Southwark was one of the first attempts to produce fertilizer from town wastes in the U.K.

No detailed information was given on either of the Dano plants in Edinburgh. The reason for this was because the Dano plant at Seafield had been run entirely as an experimental unit and the larger Dano plant at Craigmillar was still under construction at the time of publication.

Mr. Perkins has made a comparison of the costs of three composting systems, and it appears that the larger Dano plant at Craigmillar will have the lowest capital and running costs of all the methods. It must be remembered however, both Jersey and Kirkconnel are treating larger quantities of sewage sludge than the Dano system and that the compost produced from Jersey and Kirkconnel is more stabilised than the product from the Edinburgh plants. The Dano method is a simple and compact process which rapidly starts aerobic fermentation; the product from the Dano cylinder must be matured before it can be used as a general fertilizer.

a. Proc. Paper 1852, November, 1958, by C. A. Gordon.

1. Project Engr., Pentagon Const. Maritime Ltd., N. S. Canada.

TREATMENT OF LIQUID RADIOACTIVE WASTES[a]

Discussion by P. Dejonghe and Pierre Cohen

P. DEJONGHE.[1]—During the last few months we have effectively operated the complete installation in a different way from what has been reported in the paper. In fact, the intermediate level wastes have been treated in the proposed installation, but the chemical methods have been very much adapted. The treatment is actually like this:

- in the pretreatment storage tanks : addition of specific reagents for radioisotopes which are not removed by the usual flocculation methods :
  - $BaCl_2$ for the removal of S^{x}
  - $CuSO_4$ (60 ppm) and K_4 $Fe(CN)_6$(50 ppm) at pH between 3 and 9 for the removal of radiocesium. The precipitates are maintained in suspension and only removed in the first flocculator.
- in the first flocculator : clarification of the water with $FeCl_3$, 100 ppm
- in the second flocculator : treatment with CaO and Na_3PO_4 at pH 11.

The results which have been obtained now during several months are:

α removal : > 99%
B-y removal : ± 98%
Sr removal : ± 99%

A pilot test (700 1/hr) is now running on lignite. The above treated water is slightly acidified with H_2SO_4 and then passed through open lignite-beds. Lignite has that way already been used for over 2.000 bedvolumes.

By this combination the obtained results are:

α removal : > 99,9%
By removal : > 99 %
Sr removal : > 99,9%

It will probably not be necessary to use this combination for intermediate wastes, although it will act there as a safety. It will essentially be used for treating the higher level effluents (± 1 μ c/ml).

PIERRE COHEN.[2]—Under the section entitled "France" it is apparent that, in line 6, the value of 89% should be changed to 80%.

In this same section it stated that the treatment of low level liquid radioactive wastes at Saclay follows British practice very closely. This is felt to

a. Proc. Paper 1930, January, 1959, by C. Straub.

1. Centre D'etudes de L'energie Nucleaire Gif-Sur-Yvette, France.
2. Industrial Chemist, Atomic Energy Comm., Center for Nuclear Studies at Saclay, Gif-sur-Yvette, France.

be in error. At Saclay we try, as far as possible, to use an inexpensive treatment: 100 ppm phosphate, 100 ppm tannin, neutralizing by soda. When there is an important quantity of a certain radio-element, we use other co-precipitating adjuvants. For example, for Te^{127} we precipitate by means of $Pb\,SO_4$ in an alkaline medium. For limes including high percentages of Cs^{139} or Sr^{90} we precipitate by means of strontium phosphate (pH = 12.8) and nickel ferro-cyanide (pH = 8).

HYDROLOGY OF URBAN RUNOFF[a]

Corrections by A. L. Tholin and Clint J. Keifer

CORRECTIONS.—In the March Journal of the Sanitary Engineering Division there appeared, on pages 70 and 71, a figure which was marked "Fig. 9" but which was, in fact, a duplicate of Fig. 2. The correct Fig. 9 is reproduced herewith on the following page.

---

a. Proc. Paper 1984, March, 1959, by A. L. Tholin and Clint J. Keifer.

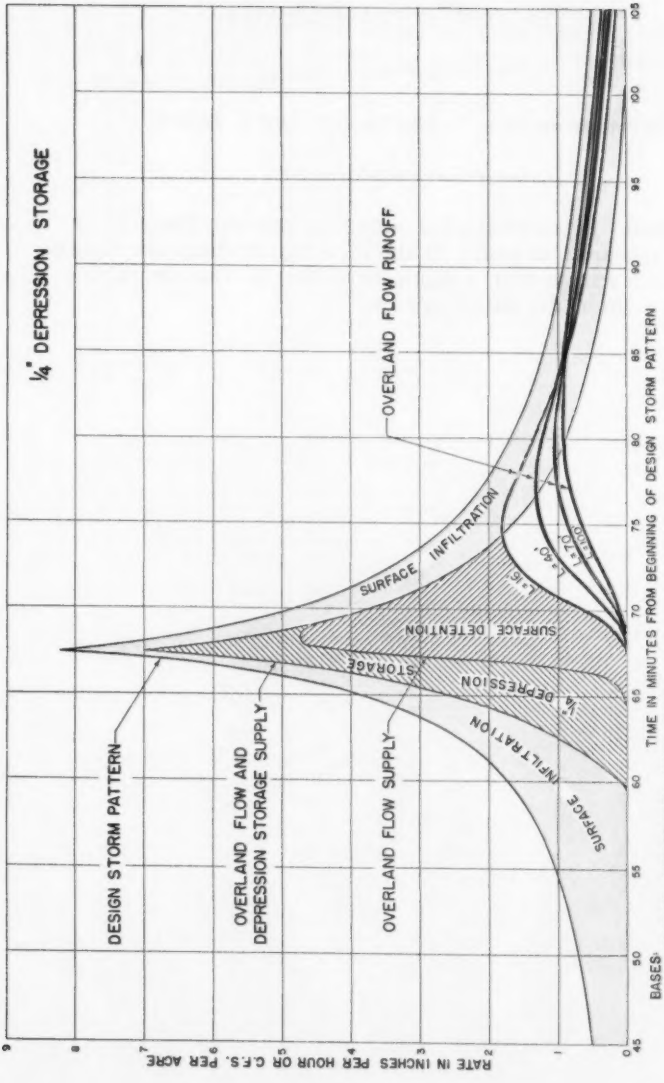


FIG 9 – OVERLAND FLOW ON PERVIOUS AREAS

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

VOLUME 84 (1958)

JULY: 1692(EM3), 1693(EM3), 1694(ST4), 1695(ST4), 1696(ST4), 1697(SU2), 1698(SU2), 1699(SU2), 1700(SU2), 1701(SA4), 1702(SA4), 1703(SA4), 1704(SA4), 1705(SA4), 1706(EM3), 1707(ST4), 1708(ST4), 1709(ST4), 1710 (ST4), 1711(ST4), 1712(ST4), 1713(SU2), 1714(SA4), 1715(SA4), 1716(SU2), 1717(SA4), 1718(EM3), 1719 (EM3), 1720(SU2), 1721(ST4)[c], 1722(ST4), 1723(ST4), 1724(EM3)[c].

AUGUST: 1725(HY4), 1726(HY4), 1727(SM3), 1728(SM3), 1729(SM3), 1730(SM3), 1731(SM3), 1732(SM3), 1733 (PO4), 1734(PO4), 1735(PO4), 1736(PO4), 1737(PO4), 1738(PO4), 1739(PO4), 1740(PO4), 1741(PO4), 1742 (PO4), 1743(PO4), 1744(PO4), 1745(PO4), 1746(PO4), 1747(PO4), 1748(PO4), 1749(PO4).

SEPTEMBER: 1750(IR3), 1751(IR3), 1752(IR3), 1753(IR3), 1754(IR3), 1755(ST5), 1756(ST5), 1757(ST5), 1758 (ST5), 1759(ST5), 1760(ST5), 1761(ST5), 1762(ST5), 1763(ST5), 1764(ST5), 1765(WW4), 1766(WW4), 1767 (WW4), 1768(WW4), 1769(WW4), 1770(WW4), 1771(WW4), 1772(WW4), 1773(WW4), 1774(IR3), 1775(IR3), 1776(SA5), 1777(SA5), 1778(SA5), 1779(SA5), 1780(SA5), 1781(WW4), 1782(SA5), 1783(SA5), 1784(IR3)[c], 1785(WW4)[c], 1786(SA5)[c], 1787(ST5)[c], 1788(IR3), 1789(WW4).

OCTOBER: 1790(EM4), 1791(EM4), 1792(EM4), 1793(EM4), 1794(EM4), 1795(HW3), 1796(HW3), 1797(HW3), 1798(HW3), 1799(HW3), 1800(HW3), 1801(HW3), 1802(HW3), 1803(HW3), 1804(HW3), 1805(HW3), 1806(HY5), 1807(HY5), 1808(HY5), 1809(HY5), 1810(HY5), 1811(HY5), 1812(SM4), 1813(SM4), 1814(ST6), 1815(ST6), 1816(ST6), 1817(ST6), 1818(ST6), 1819(ST6), 1820(ST6), 1821(ST6), 1822(EM4), 1823(PO5), 1824(SM4), 1825(SM4), 1826(SM4), 1827(ST6)[c], 1828(SM4)[c], 1829(HW3)[c], 1830(PO5)[c], 1831(EM4)[c], 1832(HY5)[c].

NOVEMBER: 1833(HY6), 1834(HY6), 1835(SA6), 1836(ST7), 1837(ST7), 1838(ST7), 1839(ST7), 1840(ST7), 1841(ST7), 1842(SU3), 1843(SU3), 1844(SU3), 1845(SU3), 1846(SU3), 1847(SA6), 1848(SA6), 1849(SA6), 1850 (SA6), 1851(SA6), 1852(SA6), 1853(SA6), 1854(ST7), 1855(SA6)[c], 1856(HY6)[c], 1857(ST7)[c], 1858(SU3)[c].

DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4), 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867 (ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876 (WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(HY7)[c], 1881(SM5)[c], 1882(ST8)[c], 1883(PP1)[c], 1884(WW5)[c], 1885(CP2)[c], 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

VOLUME 85 (1959)

JANUARY: 1892(AT1), 1893(AT1), 1894(EM1), 1895(EM1), 1896(EM1), 1897(EM1), 1898(EM1), 1899(HW1), 1900(HW1), 1901(HY1), 1902(HY1), 1903(HY1), 1904(HY1), 1905(PL1), 1906(PL1), 1907(PL1), 1908(PL1), 1909(ST1), 1910(ST1), 1911(ST1), 1912(ST1), 1913(ST1), 1914(ST1), 1915(ST1), 1916(AT1)[c], 1917(EM1)[c], 1918(HW1)[c], 1919(HY1)[c], 1920(PL1)[c], 1921(SA1)[c], 1922(ST1)[c], 1923(EM1), 1924(HW1), 1925(HW1), 1926 (PL1), 1927(HW), 1928(HW1), 1929(SA1), 1930(SA1), 1931(SA1), 1932(SA1).

FEBRUARY: 1933(HY2), 1934(HY2), 1935(HY2), 1936(SM1), 1937(SM1), 1938(ST2), 1939(ST2), 1940(ST2), 1941(ST2), 1942(ST2), 1943(ST2), 1944(ST2), 1945(HY2), 1946(PO1), 1947(PO1), 1948(PO1), 1949(PO1), 1950(HY2)[c], 1951(SM1)[c], 1952(ST2)[c], 1953(PO1)[c], 1954(CO1), 1955(CO1), 1956(CO), 1957(CO1), 1958(CO1), 1959(CO1).

MARCH: 1960(HY3), 1961(HY3), 1962(HY3), 1963(IR1), 1964(IR1), 1965(IR1), 1966(IR1), 1967(SA2), 1968(SA2), 1969(ST3), 1970(ST3), 1971(ST3), 1972(ST3), 1973(ST3), 1974(ST3), 1975(ST3), 1976(WW1), 1977(WW1), 1978(WW1), 1979(WW1), 1980(WW1), 1981(WW1), 1982(WW1), 1983(WW1), 1984(SA2), 1985(SA2)[c], 1986 (IR1)[c], 1987(WW1)[c], 1988(ST3)[c], 1989(HY3)[c].

APRIL: 1990(EM2), 1991(EM2), 1992(EM2), 1993(HW2), 1994(HY4), 1995(HY4), 1996(HY4), 1997(HY4), 1998 (SM2), 1999(SM2), 2000(SM2), 2001(SM2), 2002(ST4), 2003(ST4), 2004(ST4), 2005(ST4), 2006(PO2), 2007 (HW2)[c], 2008(EM2)[c], 2009(ST4)[c], 2010(SM2)[c], 2011(SM2)[c], 2012(HY4)[c], 2013(PO2)[c].

MAY: 2014(AT2), 2015(AT2), 2016(AT2), 2017(HY5), 2018(HY5), 2019(HY5), 2020(HY5), 2021(HY5), 2022(HY5), 2023(PL2), 2024(PL2), 2025(PL2), 2026(PP1), 2027(PP1), 2028(PP1), 2029(PP1), 2030(SA3), 2031(SA3), 2032(SA3), 2033(SA3), 2034(ST5), 2035(ST5), 2036(ST5), 2037(ST5), 2038(PL2), 2039(PL2), 2040(AT2)[c]. 2041(PL2)[c], 2042(PP1)[c], 2043(ST5)[c], 2044(SA3)[c], 2045(HY5)[c], 2046(PP1), 2047(PP1).

JUNE: 2048(CP1), 2049(CP1), 2050(CP1), 2051(CP1), 2052(CP1), 2053(CP1), 2054(CP1), 2055(CP1), 2056 (HY6), 2057(HY6), 2058(HY6), 2059(IR2), 2060(IR2), 2061(PO3), 2062(SM3), 2063(SM3), 2064(SM3), 2065 (ST6), 2066(WW2), 2067(WW2), 2068(WW2), 2069(WW2), 2070(WW2), 2071(WW2), 2072(CP1)[c], 2073(IR2)[c], 2074(PO3)[c], 2075(ST6)[c], 2076(HY6)[c], 2077(SM3)[c], 2078(WW2)[c].

JULY: 2079(HY7), 2080(HY7), 2081(HY7), 2082(HY7), 2083(HY7), 2084(HY7), 2085(HY7), 2086(SA4), 2087 (SA4), 2088(SA4), 2089(SA4), 2090(SA4), 2091(EM3), 2092(EM3), 2093(EM3), 2094(EM3), 2095(EM3), 2096 (EM3), 2097(HY7)[c], 2098(SA4)[c], 2099(EM3)[c], 2100(AT3), 2101(AT3), 2102(AT3), 2103(AT3), 2104(AT3), 2105(AT3), 2106(AT3), 2107(AT3), 2108(AT3), 2109(AT3), 2110(AT3), 2111(AT3), 2112(AT3), 2113(AT3), 2114(AT3), 2115(AT3), 2116(AT3), 2117(AT3), 2118(AT3), 2119(AT3), 2120(AT3), 2121(AT3), 2122(AT3), 2123(AT3), 2124(AT3), 2125(AT3).

c. Discussion of several papers, grouped by divisions.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1959

PRESIDENT

FRANCIS S. FRIEL

VICE-PRESIDENTS

Term expires October, 1959:
WALDO G. BOWMAN
SAMUEL B. MORRIS

Term expires October, 1960:
PAUL L. HOLLAND
LLOYD D. KNAPP

DIRECTORS

Term expires October, 1959:
CLINTON D. HANOVER, Jr.
E. LELAND DURKEE
HOWARD F. PECKWORTH
FINLEY B. LAVERTY
WILLIAM J. HEDLEY
RANDLE B. ALEXANDER

Term expires October, 1960:
PHILIP C. RUTLEDGE
WESTON S. EVANS
TILTON E. SHELBURNE
CRAIG P. HAZELET
DONALD H. MATTERN
JOHN E. RINNE

Term expires October, 1961:
THOMAS J. FRATAR
EARL F. O'BRIEN
DANIEL B. VENTRES
CHARLES W. BRITZIUS
WAYNE G. O'HARRA
FRED H. RHODES, JR.
N. T. VEATCH

PAST PRESIDENTS

Members of the Board

MASON G. LOCKWOOD
LOUIS R. HOWSON

EXECUTIVE SECRETARY

WILLIAM H. WISELY

ASSISTANT SECRETARY

E. LAWRENCE CHANDLER

ASSISTANT TREASURER

ENOCH R. NEEDLES

PROCEEDINGS OF THE SOCIETY

HAROLD T. LARSEN
Manager of Technical Publications

PAUL A. PARISI
Editor of Technical Publications

MARVIN SCHECHTER
Assistant Editor of Technical Publications

COMMITTEE ON PUBLICATIONS

HOWARD F. PECKWORTH, *Chairman*

PHILIP C. RUTLEDGE, *Vice-Chairman*

E. LELAND DURKEE
CHARLES W. BRITZIUS
TILTON E. SHELBURNE
FRED H. RHODES, JR.

SA 4

JULY 1959 — 28 NO. SA 4
VOLUME 85 PART 2

Your attention is invited

NEWS OF THE SANITARY ENGINEERING DIVISION OF ASCE

JOURNAL OF THE SANITARY ENGINEERING DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

DIVISION ACTIVITIES

SANITARY ENGINEERING DIVISION

Proceedings of the American Society of Civil Engineers

NEWS

July, 1959

EXECUTIVE COMMITTEE MEETING SANITARY ENGINEERING DIVISION

A meeting of the Sanitary Engineering Division Executive Committee was held in Chicago on April 18. The following summary of the minutes will be of interest to Division members.

EXECUTIVE COMMITTEE

The Executive Committee appointed David H. Howells to become Secretary of the Division at the close of the Annual Meeting in October 1959.

WATER RESOURCES COORDINATING COMMITTEE

Richard Kennedy, Sanitary Engineering Division representative to the ASCE Water Resources Coordinating Committee, has given our Committee on Water Supply Engineering under the Chairmanship of Robert D. Mitchell the task of reorganizing the Committee in line with the Water Resources Coordinating Committee's recommendations. This involves undertaking all of the items of water resources planning which will be under the cognizance of the Sanitary Engineering Division.

The revised Statement of Purpose for the Water Supply Engineering Committee as adopted by the Executive Committee is as follows:

> WATER SUPPLY ENGINEERING: COMMITTEE ON -- Purpose; to study, stimulate or sponsor research, and report on the problems connected with providing an adequate supply of water for community needs; methods of integrating these needs into regional, area or local planning; methods of control, treatment and construction to develop, protect or reclaim water for full beneficial utilization particularly as they relate to water for domestic and industrial use, recreation and wild life preservation; correlate work done in the field of sanitary engineering with that being done in other fields of engineering and science. The committee, by means

Note: No. 1959-28 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 85, SA 4, July, 1959.

of task committees or otherwise, shall act as a clearing house for the coordination and dissemination of information on these subjects at meetings and conferences.

This statement is now being reviewed by the Water Resources Committee, prior to being sent to the ASCE Division Activities Committee for their consideration.

INDUSTRIAL WASTES PRACTICES COMMITTEE

The Industrial Wastes Committee has been completely reorganized by Lewis Young, and S. Leary Jones has accepted the Committee Chairmanship. Mr. Young's report to the Executive Committee is summarized below:

Committee Membership

Frank P. Coughlan	Roy F. Weston
Ed. Franklin Eldridge	S. Leary Jones, Chairman
Paul D. Haney	Lewis A. Young, Contact
David A. Robertson, Jr.	Member, Executive Committee
David F. Smallhorst	

The purpose of the Committee will be to develop and guide the overall industrial wastes practices program. Special task forces will be appointed by the Committee for the preparation of reports, papers, and memorandums on industrial waste practices in particular fields. The Committee also plans to develop industrial waste guides for each type of industry producing significant waste flows. These guides will include a description of the process, type of wastes, strength and quantity of individual and combined wastes, treatment and recovery practices, summaries of present treatment and recovery works, specific examples, and references.

RESEARCH

Nelson L. Nemerow was commended for the excellent work he is accomplishing with his reports.

SANITARY ENGINEERING CONFERENCE

Work on the Conference is well under way. Publicity is being arranged and every effort is being made to assure that the Division's first Conference, in Cincinnati, will be thoroughly successful. The Executive Committee will meet in Cincinnati the day before the Conference instead of at the annual meeting in October, 1959. It was decided that as many of the Division Committees as possible should attempt to meet at the same time so that they will have an opportunity to meet with the Executive Committee.

RENO CONVENTION

Mr. J. C. Jennings was appointed a short term member of the Program Committee for the Reno Convention.

AMERICAN INTERSOCIETY SANITARY ENGINEERING BOARD

Mr. Thomas Camp was reappointed to the Board.

* *

SEE YOU IN CINCINNATI

ON

JANUARY 6, 7, and 8 AT THE

SANITARY ENGINEERING CONFERENCE

* *

DID YOU KNOW THAT

Dr. Arthur L. Miller, former Congressman from Nebraska, has been appointed Director of the Department of Interior's Office of Saline Water. Dr. Miller was chairman of the Interior Committee during the 83rd Congress. From 1919 until his election to the House of Representatives in 1942, Dr. Miller practiced medicine and surgery in Kimball County, Nebraska.

David S. Jenkins, former Director, will continue with the Office of Saline Water as an Assistant Director. His duties will include extensive work in the negotiation of cooperative agreements with States and local communities as well as on problems relating to the saline water program in its international aspects.

Professor P. H. McGauhey of the University of California, recently returned from Kuwait where he and Mr. F. E. Bruce of the Imperial College of Science and Technology of the University of London spent several weeks as special consultants to the Kuwait Oil Company on public health engineering problems.

Mark D. Hollis has been appointed to the newly created position of Associate Chief for Sanitary Engineering in the Bureau of State Services of the U. S. Public Health Service. Mr. Hollis will serve as staff adviser to the Chief of the Bureau of State Services in connection with environmental public health programs which are of growing importance to the Public Health Service. He will also continue as Chief Sanitary Engineer Officer of the Service.

Wesley E. Gilbertson has been appointed chief of the Public Health Service's new Division of Engineering Services. This Division includes activities relating to milk and food sanitation, general engineering, engineering resources, the engineering aspects of air pollution, and the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

Gordan E. McCallum has been appointed Chief of the new Division of Water Pollution Control recently created within the U. S. Public Health Service.

Richard R. Kennedy and Robert M. Kennedy of the Engineering Office of Clyde C. Kennedy have announced modification of the name of the consulting engineering office to KENNEDY ENGINEERS. The Technical staff, facilities, and office locations will remain the same.

Herbert M. Bosch, University of Minnesota professor of environmental sanitation in the school of public health, received the University of Missouri's honor award for distinguished service in engineering at Engineering Day activities recently in Columbia, Missouri.

Colonel Alvin F. Meyer, Jr., Senior Industrial Hygiene Engineer, Office of the Surgeon, Headquarters Strategic Air Command, Offutt Air Force Base, Nebraska, has been elected chairman of the Offutt Chapter of the Institute of Aeronautical Sciences. This election discloses the interest and importance attributed to problems of environmental health and control of environmental stresses in modern aviation. In addition to concern for traditional problems of sanitation, industrial hygiene aspects of aircraft maintenance and missile maintenance, the new developments in space travel and high speed aircraft performance require the use of the skills of sanitary and industrial hygiene engineering in coping with many of the problems of the aeronautical industry.

Karl M. Mason, director of the Pennsylvania State Health Department's environmental health bureau, has been appointed chairman of the transportation subcommittee of the Governor's Inter-Departmental Committee on Atomic Energy. Represented on the subcommittee in addition to the Health Department are the Public Utility Commission, Revenue Department, State Police, Labor and Industry, Highways and Justice Departments and the Turnpike Commission.

Walter W. Saxton, who was recently appointed chief engineer of the Washington Pollution Control Commission, has resigned to become associated with the consulting firm of Stevens and Thompson, Portland, Oregon. He will be located in Seattle, where a new office has been opened.

Don Gray, of Gray and Osborne, consulting engineers of Yakima, Washington, was elected chairman of the Sanitary Engineering Advisory Committee of the State College of Washington. He replaces R. Trumbull Smith, manager of the Seattle office of Wallace and Tiernan, Inc.

* * * *

SANITARY ENGINEERING EDUCATION

CALTECH TO CONSTRUCT EXTENSIVE NEW ENGINEERING LABORATORIES

The California Institute of Technology has received a $2.5 million gift for the construction of a new engineering building from the W. M. Keck Foundation and the Superior Oil Company. This gift is the largest received to date in Caltech's current development campaign, and the largest the Institute has ever received for building purposes. The new building will be a five-story structure with two floors below ground. Its major units will be: a Laboratory of Engineering Materials, a Laboratory of Sanitary Engineering, and a Laboratory of Hydraulics and Water Resources. It will be named the W. M. Keck Engineering Laboratories.

Approximately 40,000 square feet will be devoted to sanitary engineering and water resources. In the sanitary engineering area, there will be one laboratory for sanitary bacteriology and biology, one for sanitary chemistry, another laboratory for environmental sanitation, and finally a large one for unit operations in the sanitary field. In addition, there will be a rather large laboratory devoted to research in ground water hydraulics. When finished, they should represent the finest sanitary engineering laboratory facilities in the country, outside of the Robert A. Taft Sanitary Engineering Center in Cincinnati.

SANITARY ENGINEERING AT IOWA STATE COLLEGE

The Board of Regents at Iowa State College has recently approved a change in name to Iowa State University of Science and Technology. Until approved by the State Legislature and Governor, however, the shorter and more familiar title will prevail.

At Iowa State, sanitary engineering is a part of the curriculum in Civil Engineering, but instruction and research are carried on with the cooperation of the Department of Bacteriology. The present civil engineering curriculum provides a general coverage of the profession without the use of options of areas of specilization. Thus, all students take courses in sanitary bacteriology, hydrology, water supply, and sewerage. Specialization in sanitary engineering takes place at the graduate level. The College offers work leading to both the M.S. and Ph.D. in Sanitary Engineering. The staff in sanitary engineering includes the following:

1. Dr. E. Robert Baumann, Professor of Civil (Sanitary) Engineering B. S. (Michigan), B.S., M.S., Ph.D (Illinois)
2. Paul E. Morgan, Associate Professor of Civil (Sanitary) Engineering B.S., M.S. (Iowa State College)
3. John L. Cleasby, Assistant Professor of Civil Engineering B.S., M.S. (Wisconsin)
4. Charles S. Oulman, Instructor of Civil Engineering B.S. (Iowa State College)
5. Dr. Russell J. Beers, Assistant Professor of Bacteriology B.S., M.S. (Nebraska), Ph.D (Illinois)

During 1959-60, Dr. E. Robert Baumann, who is director of sanitary engineering here, will be on a leave-of-absence to accept a National Science Foundation Science Faculty Fellowship for postdoctoral study abroad. Dr. Baumann will sail for England with his family about September 3, 1959 for 12 months of postdoctoral study and research at the University of Durham, King's College, Newcastle-upon-Tyne, England. He will serve as Visiting Professor of Civil Engineering and will study there in the areas of microbiology, biochemistry, and statistics under Peter C. G. Isaac, Senior Lecturer in Public Health Engineering at King's College.

During Dr. Baumann's leave-of-absence, the work in sanitary engineering here will be directed by Professor Harold E. Babbitt who has been appointed as Visiting Professor of Civil (Sanitary) Engineering. Professor Babbitt is Professor Emeritus of Sanitary Engineering at the University of Illinois, having retired there in 1954, and is presently Visiting Professor of Civil Engineering at the University of Missouri. He will be at Iowa State College from September 1, 1959-May 30, 1960.

At present, the program of sanitary engineering research at Iowa State College involves work in the following areas:

1. Plant-Scale Studies of Preaeration in Sewage Treatment N.I.H. Grant RG-4505 (C2)
2. Operation of Pressure vs Vacuum Diatomite Filters N.I.H. Grant RG-5958 (A)

3. Determination of Optimum Filtration Rates for Rapid Sand Filters

4. Small Water Supply Studies
   a) Supercholorination-Dechlorination of Small Water Supplies-Everpure, Inc. Research Grant
   b) Characteristics of Farm Ponds as a Domestic Water Supply-State supported

At present, there are 5 PH.D and 6 M.S. candidates for graduate degrees in sanitary engineering at Iowa State.

SCHEDULE OF TRAINING COURSES AT THE ROBERT A. TAFT SANITARY ENGINEERING CENTER

July 6 - 10, 1959
RADIOLOGICAL HEALTH FOR X-RAY TECHNICIANS (49R)

July 13 - 24, 1959
ADVANCED TRAINING FOR ENGINEERS AND SCIENTISTS FROM FOREIGN COUNTRIES (47S)

August 17 - 21, 1959
RECENT DEVELOPMENTS IN WATER BACTERIOLOGY (4W)

September 14 - 18, 1959
RADIONUCLIDES IN FOODS (59RM)

September 21 - October 2, 1959
COMMUNITY AIR POLLUTION (53A)

October 5 - 16, 1959
BASIC RADIOLOGICAL HEALTH (6R)

October 19 - 23, 1959
RADIONUCLIDE PROTECTION (60R)

October 26 - 30, 1959
X-RAY PROTECTION (61R)

October 26 - November 6, 1959
PLANKTON IDENTIFICATION AND CONTROL (19W)

November 9 - 20, 1959
BASIC RADIOLOGICAL HEALTH (6R)

November 9 - 13, 1959
CONTROL OF PARTICULATE EMISSIONS (62A)

November 16 - 20, 1959
CONTROL OF GASEOUS EMISSIONS (63A)

November 30 - December 11, 1959
CHEMICAL ANALYSES FOR WATER QUALITY (3W)

November 30 - December 11, 1959
MEDICAL ASPECTS OF RADIOLOGICAL HEALTH (50R)

January 11 - 22, 1960
BASIC RADIOLOGICAL HEALTH (6R)

January 11 - 22, 1960
ANALYSIS OF ATMOSPHERIC POLLUTANTS (38A)

January 25 - 29, 1960
RECENT DEVELOPMENTS IN WATER BACTERIOLOGY (4W)

January 25 - 29, 1960
RADIOACTIVE POLLUTANTS IN AIR (39 AR)

February 1 - 5, 1960
MICROBIOLOGICAL AND CHEMICAL EXAMINATION OF MILK AND DAIRY PRODUCTS (2M)

February 8 - 12, 1960
LABORATORY METHODS FOR PREVENTION AND CONTROL OF FOOD-BORNE DISEASE (9M)

February 8 - 12, 1960
RADIOACTIVE POLLUTANTS IN WATER (20WR)

February 15 - 19, 1960
RADIONUCLIDES IN WATER (65RW)

February 15 - 26, 1960
MICROSCOPIC ANALYSES OF AIR-BORNE PARTICULATES (64A)

February 29 - March 11, 1960
WATER QUALITY MANAGEMENT-SANITARY ENGINEERING ASPECTS (1W)

March 14 - 25, 1960
SANITARY ENGINEERING ASPECTS OF NUCLEAR ENERGY (35R)

April 4 - 15, 1960
ATMOSPHERIC AND SOURCE SAMPLING (52A)

April 18 - 22, 1960
RADIONUCLIDES IN FOODS (59 RM)

April 25 - 29, 1960
ANALYSIS OF ATMOSPHERIC INORGANICS (54A)

May 2 - 6, 1960
ANALYSIS OF ATMOSPHERIC ORGANICS (55A)

May 2 - 13, 1960
BASIC RADIOLOGICAL HEALTH (6R)

May 9 - 20, 1960
ORGANIC INDUSTRIAL WASTES CHARACTERIZATION (57W)

May 16 - 26, 1960
REACTOR ENVIRONMENTAL HEALTH PROBLEMS (36R)

May 23 - 27, 1960
SHELLFISH SANITATION (44MW)

May 23 - 27, 1960
INORGANIC INDUSTRIAL WASTES CHARACTERIZATION (10W)

June 6 - 18, 1960
ADVANCED TRAINING FOR SANITARY ENGINEERING RESERVE OFFICERS: COMMUNITY AIR POLLUTION (53A)

June 13 - 24, 1960
AQUATIC BIOLOGY FOR ENGINEERS (12W)

June 18 - July 1, 1960
ADVANCED TRAINING FOR SANITARY ENGINEERING RESERVE OFFICERS: BASIC RADIOLOGICAL HEALTH (6R)

These courses are intended for personnel engaged in the appropriate field who desire to obtain training in the latest techniques and newest developments in their areas. Fundamental information normally acquired at the undergraduate level is not usually included in the courses.

Applications and specific information pertaining to the various courses may be obtained from the Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

TRAINING INSTITUTE AT WESTERN MASSACHUSETTS PUBLIC HEALTH CENTER

A summer training institute will be held at the new Western Massachusetts Public Health Center in Amherst on the campus of the University of Massachusetts beginning July 20, 1959. The Institute, consisting of four courses, will be sponsored by the Public Health Service, the University of Massachusetts and the Massachusetts Department of Public Health.

Brochures are being prepared and will be sent out to persons and agencies concerned with the topics to be considered during the four courses.

Dates and titles of courses are as follows:

July 20 - July 31	Basic Radiological Health
July 27 - August 7	Water Pollution Biology for Engineers
August 3 - August 14 . . .	Air Pollution Control. (For engineers and other professional personnel engaged in planning and operation of atmospheric and source sampling programs.)
August 10 - August 14 . .	Bio-assay and Pollution Ecology. (Special course for Federal and State conservation personnel on the effects of pollution on fish life.)

UNIVERSITY OF MICHIGAN PRESENTS SHORT COURSE ON INDUSTRIAL WATER CONSERVATION

A short course on Industrial Water Conservation was held at the University of Michigan School of Public Health on June 8 and 9, 1959. This was presented to meet the need expressed by representatives of various industries for exploration of just what is being done and what can be done by industry to cut down on its use of water.

CONFERENCE ON GREAT LAKES RESEARCH

The Horace H. Rackham School of Graduate Studies at Ann Arbor, Michigan was the site of the Third Conference on Great Lakes Research held on May 6 and 7, 1959. Sponsored by the Great Lakes Research Institute of the University of Michigan, the Conference covered the present status of knowledge of the Great Lakes and future research needs.

BIO-OXIDATION OF ORGANIC WASTES

The Civil Engineering Department of Manhattan College offered its fourth one-week course on the Theory and Design of Biological Waste Treatment during the week of June 15, 1959. The objective of the course was to present the fundamentals of bio-oxidation which will serve as a framework for the analysis, design, and operation of biological waste treatment facilities. Emphasis was placed on applications of these principles to several wastes from industries including pulp and paper, pharmaceutical, canning and chemical.

CONFERENCE ON RADIOACTIVITY AND THE ENVIRONMENT

The first of a series of conferences on radiological health was held at the Nuclear Science Center of Rutgers University on April 9 and 10, 1959. These conferences have arisen out of the concern of public health officials about the increasing amount of radioactive matter in the environment. This conference on Radioactivity and the Environment was designed for persons associated with water supplies, liquid and gaseous wastes. It provided the necessary background for information on analytical techniques and described present and future programs of detection and protection.

HEALTH ENGINEERING IN THE SPACE AGE

The Civil Engineering Department of the University of Texas was joint sponsor of the University's Fifth Occupational Health Conference held on May 8, 1959 in Austin. The Conference included lectures on new industrial hygiene problems, instrument calibration, noise exposure criteria for preservation of health, toxicology of newer heavy metals, welding hazards, industrial health insurance, medical concern in space flight, and repiratory protection for radioactive and other highly toxic aerosols.

TRAINING COURSE ORGANIZED FOR STATE HEALTH DEPARTMENT SANITARY ENGINEERS

A two-week training course for Pennsylvania State Health Department sanitary engineers was conducted in Harrisburg on April 13 through 24. The course featured aquatic biology, mine drainage, sanitary chemistry, hydraulics, mathematics, water treatment, sewage treatment and industrial waste treatment. In addition to instructors from the Health Department, Dr. Charles Renn, professor of sanitary engineering, Johns Hopkins University, and Samuel Zack, member of Gannett, Fleming, Corddry and Carpenter, consulting engineers, were guest instructors.

* * * *

SANITARY ENGINEERING RESEARCH

SPECIAL RESEARCH MEETING ON INDUSTRIAL WASTES

The Special Research Meeting of the National Technical Task Committee on Industrial Wastes, held at the U. S. Public Health Service's Robert A. Taft Sanitary Engineering Center on April 27-28, closed on a note of optimism concerning progress in water pollution. The members of the Committee, however, restated their awareness of the need for close cooperation between government and industry in meeting the problems in water supply and water pollution now facing the Nation.

The 60 scientists and business executives in attendance met to review current industrial waste treatment research and to be briefed on the aim, scope, and direction of water research at the Sanitary Engineering Center. Ray S. Glynn of the Association of American Railroads and NTTCIW Chairman stated the special research meeting was called "in recognition of the vital importance of keeping industrial waste treatment research current with the expanding population and increasingly complex technology of modern industry." The group functions as a central clearing house on industrial waste and water pollution information and to maintain priorities for research in this field.

Based on the reports received by the NTTCIW during the special meeting, the Committee concluded that improved communication on water pollution between government and industry was an important requirement for future progress, a point made during the opening session by both Harry G. Hansoh, Director of the Center, and Bernard B. Berger, Chief, Water Supply and Water Pollution Research.

Harry A. Faber, Research Grants Coordinator for the PHS Engineering Resources Program, told the group that research grants in the water field awarded during the present fiscal year now total approximately $1,350,000 and support 117 projects. He presented the specific information on work underway, and related it to the Committee's recommendations.

The Sanitary Engineering Center reports on research dealt with activities in waste characterization, industrial waste treatment, stream studies, sewage treatment, and water treatment.

The specific projects reported on were as follows:

Waste characterization: studies on the treatability and persistence of specific organic compounds, fish bioassay studies, and characterization of wastes from catalytic cracking of petroleum.

Industrial wastes treatment: Sanitary Engineering Center consultation with industry, studies on the effect of toxic heavy metals on biological treatment processes, studies on the conversion of sugars in spent sulfite liquor to fumaric acid, studies on the selection and adaptation of microorganisms to degrade specific wastes, and development of an industrial waste guide for uranium ore refineries.

Stream studies: studies on organic contaminants, microbial contaminants, dissolved oxygen requirement of fish and other cooperative studies at the Corvallis field station, and effect of impoundment on dissolved oxygen.

Sewage treatment: waste stabilization ponds, studies on bio-oxidation surfaces, treatment of sewage by anaerobic contact, and studies on soil absorption of liquid effluents.

Water treatment: municipal water treatment studies, and studies on nuisance organisms.

EFFECTS OF AUTO EXHAUST ON ANIMALS TESTED

Studies to determine the effects on experimental animals of short-term exposure to irradiated auto-exhaust-air mixtures are being made at the Robert A. Taft Sanitary Engineering Center. The immediate objectives are to develop sensitive tests for detecting effects in the laboratory animals, to identify the kind and measure the amount of such effects, to discover the smallest concentration of exhaust which produces measurable effects, to determine the relative contribution of various components of the exhaust to the effects observed, and to study the relationship between exposure time and concentration of the exhaust-air mixtures. If successful, these tests should provide more accurate measuring sticks for future long-term experiments, indicate areas where more biological research is needed, help in the biological evaluation of devices for controlling auto-exhaust emissions, and possibly develop more effective clinical tests for air pollution epidemiologic surveys.

GROWING PLANTS AS AIR POLLUTION INDICATORS

A greenhouse, with adjoining laboratory space, has been installed at the Taft Sanitary Engineering Center. Under the supervision of Dr. C. Stafford Brandt, USDA, Chief of the Agricultural Unit of Air Pollution Engineering Research, Dr. Robert G. Emge will operate the new greenhouse with a double purpose. First, it will aid in the search for extra-sensitive plants which can be used as indicators of air pollution. Second, in the automobile test facility which will be completed in the near future, selected plants will be exposed to the effects of non-irradiated and irradiated automobile exhausts.

SANITARY ENGINEERING RESEARCH LABORATORY - UNIVERSITY OF CALIFORNIA

Soil Absorption Systems

The scope of studies of the biological aspects of failure of septic tank percolation systems being conducted by the Research Laboratory under sponsorship of FHA has recently been widened. Under a supplementary contract, the investigation will also be concerned specifically with the effects of effluents from household aerobic treatment units on soil absorption systems. The increased use of aerobic sewage treatment systems for individual households has stimulated interest in the behavior of liquid effluents from such systems when discharged to sub-surface drainage fields or percolation wells of the type commonly used with septic tank installations. In the absence of experience with sub-surface disposal of aerated liquids, fear has been expressed that this type of effluent will rapidly air-bind the soil, thus causing the system to fail. More optimistic individuals have suggested that the very nature of aerobic decomposition insures the production of an effluent so superior to that from an anaerobic cycle of the septic tank that the requirements for ultimate disposal of the effluent may be considerably relaxed. In some cases it has been argued that tile drainage fields designed to receive

aerobic effluents can be much smaller or more heavily loaded than their counterparts which receive typical septic tank effluents. In other cases it has been proposed to discharge aerobic effluents directly to surface drainage ditches, to storm drains, or to water courses without supplementary treatment.

If either of the foregoing possibilities should prove feasible from technical and public health viewpoints, the individual home aerobic sewage treatment unit could become an attractive possibility wherever soil conditions are unsuited to conventional septic tank effluents. However, no satisfactory method has yet been devised for predicting the behavior of septic tank effluents in relation to soil characteristics, and unpredictable failures of per colation fields continue to occur with alarming frequency.

Synthetic Detergents

Recent studies on the engineering aspects of alkyl-benzene-sulfonate removal by surface stripping have demonstrated the relationship of air supply and depth of sewage to achieving maximum efficiency. Experiments have shown that for a given rate of application of air there is an optimal surface area to volume ration. A straight-line relationship indicates that the ratio is reduced with increased rate of air application. It has also been determined that for a given level of ABS removal, the amount of air required per unit volume of sewage is a constant.

At present, a surface stripping tank of considerable size is under construction. Its primary purpose will be to determine the feasibility of destruction of large quantities of foam by burning with digester gas after the foam has been channeled into a separate chamber. Attempts to destroy foam as it is being formed by substitution of methane for air with continuous surface burning were not successful due to the inability of methane to remove ABS adequately from the sewage. However, future work involving the concurrent use of both air and methane might overcome this obstacle and prove to be the most satisfactory method of foam destruction.

Algae Symbiosis

An investigation of the basic role of algal-bacterial cultures in bio-control of enclosed environments is being continued following release of the first progress report. Studies now are being conducted on the potability of reclaimed water and the value of reclaimed algae as a food supplement. Development of a new algal culture apparatus with which to carry out experiments on Phase Isolation is nearing completion. Studies will then be undertaken to investigate the permissible loadings in the new units. It is hoped that pH and turbidity control can be attained and that they will lead to design criteria permitting loading 3 to 5 times those currently used for ponds.

* * *

WATER SUPPLY AND WATER POLLUTION CONTROL

DRINKING WATER STANDARDS TO BE REVISED

On March 24-25 a group of physicians, scientists, engineers, and administrators met in Washington, D. C., to consider revision of the U. S. Public Health Service Drinking Water Standards. In view of changes in the nature and extent of impurities which are being added to the Nation's supplies as a result of greater population growths and even greater technological and industrial development, the Public Health Service has appointed this Advisory Committee to re-evaluate these Standards, which were first formulated 45 years ago and last revised in 1946.

The Public Health Service Drinking Water Standards were originally written to apply only to water used on interstate carriers and this remains their only legal basis. However, State health departments, the American Water Works Association, and the Armed Forces have accepted them as standards for public water supplies. This general acceptance makes it mandatory that they be kept current and that the basic knowledge required to deal with new problems be developed before problems become acute. In considering standards for limiting impurities in drinking water at this time, special attention was given at this meeting to the problems involved in setting limits for nonliving contaminants such as radionuclides and synthetic organics and other chemicals.

This was the first of a series of meetings scheduled for coming months by the Advisory Committee.

NEWS FROM THE OFFICE OF SALINE WATER

Annual Report of Office of Saline Water Published

The Saline Water Conversion Report for 1958 has been published and is available for public distribution, the Department of the Interior has announced. The report contains a summary of the developments during 1958 on each of the several major process groups on which research and development work was conducted. Appended to the report is a coordination table which lists all known current research and development work in the field of saline water conversion, including both that sponsored by the Department of the Interior and that sponsored by others. Copies of the report may be obtained from the Office of Saline Water, Department of the Interior, Washington 25, D. C.

Contract Approved for Saline Water Conversion Demonstration Plant

Secretary of the Interior Fred A. Seaton has announced approval of a contract for a preliminary design of a one million gallon per day saline water conversion demonstration plant. The cost-reimbursable negotiated contract, not to exceed $50,000, was awarded to W. L. Badger and Associates of Ann Arbor, Michigan. The signing of this contract follows the announcement, on March 2, of the selection of the long-tube vertical distillation process for demonstration as authorized by Public Law 85-883. This is the first of five plants that will be built by the Department. The second process to be

demonstrated will be selected on or before June 2. W. L. Badger and Associates are developers, in conjunction with the Swenson Evaporator Company, of this particular sea water conversion process. In close cooperation with the technical staff of the Office of Saline Water, the Badger firm will now proceed to establish general process conditions, including preparation of flow sheets, major items of equipment and functional drawings together with the outline of the future operational program for the LTV process.

Three More States Enter Cooperative Saline Water Research Agreements

Three separate cooperative agreements between the Department of the Interior and the States of Arizona, Florida, and Texas, were recently signed providing for mutual assistance in the study of saline water conversion problems. These agreements provide for general assistance and exchange of information between the individual States and the Office of Saline Water on development of improved saline water conversion processes and their actual potential application.

The State of California signed a cooperative agreement with the Department on April 22, 1958, and a similar agreement with the State of New Mexico was announced on January 8, 1959. Two other States, North and South Dakota have initiated actions and negotiations toward cooperative agreements of this type.

Solar Research Station Established for Sea Water Conversion

The completion of an experimental deep-basin solar still for sea water conversion was recently announced by Interior Secretary Fred A. Seaton. This is the first of three solar stills that will be tested and developed by the Battelle Memorial Institute of Columbus, Ohio, at a seashore solar research site near Port Orange, Florida. The amount of the contract with Battelle is $145,000.

The deep-basin, glass-covered still, designed by Dr. George O. G. Löf, of Denver, Colorado, covers an area of 2,500 square feet. This is of sufficient size to allow evaluation of engineering features and obtain reliable data on construction, operation and maintenance costs.

"One of the major problems of producing fresh water from the sea is the cost of conversion," Secretary Seaton said. "Distillation by means of solar heat has the advantage of eliminating the cost of the fuel energy otherwise required. Other costs, such as cost of equipment and operating costs, including amortization of plant investment, must be considered in computing the total cost of conversion. Therefore, the major objectives of this solar distillation research are reduction of equipment cost and increase in efficiency. "At the present time," the Secretary said, "it appears that the best chances for expanded use of solar stills for conversion of sea or brackish water are in isolated areas and in certain arid regions where solar intensities are high, and where conventional fuels are expensive."

According to Dr. A. L. Miller, Director of the Office of Saline Water, the two other stills provided for in the contract with Battelle are nearing completion at the Florida station. One will cover an area of 500 square feet, and the other 2,500 square feet. Both stills are of shallow basin design and make extensive use of plastic materials.

Under a cooperative agreement with the Department on solar distillation developments, E. I. DuPont de Nemours and Co., has supplied the basic designs and plastics materials for the two shallow basin stills. The larger one uses weatherable Mylar as a cover material and the smaller still has a cover of experimental film designated as Type R.

The still consists of black-bottomed basins with transparent covers. The vapor, produced from sea water in the bottom of the basins, condenses on the inside of the transparent cover and runs down to channels at the edges of the basin for collection. The three stills are expected to produce a total of about 500 gallons of fresh water per day.

The research station, located 15 miles south of Daytona Beach, was made available to the Department by the U. S. Coast Guard from the Ponce de Leon Lighthouse reservation area.

Second Sea Water Conversion Demonstration Plant May Utilize Atomic Heat

The selection of the multi-stage flash distillation process for the second saline water demonstration plant has recently been announced by the Secretary of Interior. The plant will be designed to convert sea water to fresh at an anticipated rate of at least 1 million gallons a day. The Atomic Energy Commission has been asked to provide a low-temperature atomic reactor as the heat source for this plant. The Secretary stated that the Department's studies of the feasibility of the use of atomic energy as the heat source for large-scale sea water distillation are definitely promising.

GOOD WATER FOR RURAL HOMES

The Texas Engineering Experiment Station, Texas A & M College, has released a bulletin entitled "Good Water for Rural Homes" which was developed to provide information that will enable rural dwellers to recognize and remedy defects in their individual water supplies. Authored by research engineers J. H. Sorrels and P. J. A. Zeller, the booklet covers iron removal clarification of surface waters, clearing ponds, tastes and odors, hardness and disinfection. Copies of this Bulletin, No. 140, are available from the Experimentation Station at a cost of $1.00 per copy. The address is: Mr. Louis J. Horn, Supervisor of Publications, Texas Engineering Experimentation Station, College Station, Texas.

FEDERAL TRADE COMMISSION ACTS ON "WATER CONDITIONER"

The Evis Manufacturing Company, San Francisco, was ordered by the Federal Commission on April 3 to stop falsely claiming that its "Evis Water Conditioner" had any beneficial effect on water. The Commission ruled that scientific evidence and testimony outweighed the evidence presented by "users." Its action vacated a hearing examiner's initial decision which would have dismissed the complaint, and ordered the Evis Mfg. Co. to discontinue its many claims covering such alleged benefits as corrosion control, softening, improvement of taste, odor removal, and soil improvement.

GOVERNOR PROCLAIMS "CLEAN STREAMS WEEK"

The week of May 3rd through May 9th was designated as "Clean Streams Week" by Governor David L. Lawrence of Pennsylvania. In his statement, Governor Lawrence said:

> "Clean streams are our job and our family's health. Without clean streams we will not have industry and without clean water we cannot live.
>
> "Every gallon of river water contains one quart of sewage, not including other deleterious matter, and our river beds are emerged with ever increasing poisonous sludge deposits. This we must change.
>
> "The Sanitary Water Board of our great State is leading the movement to clean up pollution. They can only go as far as the people are willing to lend aid. The people can and must provide the support. I urge our citizens to check their local communities during clean streams week and—if necessary—start local improvement action."

Concurrently with this proclamation, came an announcement by the State Health Officer, Dr. Charles L. Wilbar, that a great deal more remained to be done in Pennsylvania in the control of pollution. In spite of spending more than any other state for sewage treatment works construction during the past five years, 52 percent of its sewered municipalities continue to pollute streams with untreated sewage. Dr. Wilbar said it is essential that sewered communities still not treating their wastes begin building sewage plants immediately. He said the State Sanitary Water Board has been forced to take legal action against municipalities which have refused to comply with board orders to treat their sewage instead of dumping it raw into the state's streams.

SECRETARY OF HEALTH, EDUCATION AND WELFARE STRESSES IMPORTANCE OF WATER POLLUTION CONTROL

In his appearance before the House Public Works Committee at hearings on House Bill 3610, on April 8, Arthur S. Flemming, Secretary of Health, Education, and Welfare, cited the nation's accelerating water requirements and stated that we don't stand a chance of meeting them unless we make marked progress in the direction of cleaning up our streams and keeping them clean. He said that for forty years we have been dumping more pollution into the surface waters of the nation than we have been removing through waste treatment, and that such a situation calls for a concerted attack on the part of the federal, state and local governments, and private groups. Some of the things he thought that the federal government should do are:

1. The federal government should be in a position where it can in-season and out-of-season focus the attention of the citizens of this nation on the importance of this problem.
2. The federal government should be in a position where it can develop a comprehensive and agreed upon plan that will indicate clearly the goals that need to be reached.

3. The federal government should carry on significant research in the water pollution area and should also be in a position where it can help stimulate related research on the part of both public and private groups.

4. The federal government should recognize the important role that financial incentives can play in accelerating the construction of waste disposal plants and should help the states provide these incentives.

5. The federal government should have the authority to step in and direct action to clean up our streams whenever the interests of more than one state are involved.

In this connection, the Secretary pointed out, he had just signed the first cease and desist notice under the provisions of the 1956 Federal Water Pollution Control Act. This notice directs Sioux City, Iowa, and ten meat processing establishments in that city to cease discharging sewage, industrial, and other untreated wastes into the Missouri River. The Secretary took this action on the unanimous recommendation of an eight-member hearing board appointed under the enforcement provisions of the federal act.

DIVISION OF WATER POLLUTION CONTROL CREATED WITHIN PUBLIC HEALTH SERVICE

Secretary Arthur S. Flemming, Health, Education and Welfare, announced on April 7 that he had raised the status of water pollution control activities in the Public Health Service, by approving the creation of a Division of Water Pollution Control in the Bureau of State Services. Gordon E. McCallum, Chief of the Service's water pollution control activities is Chief of the New Division.

"The new Division," the Secretary said, "will be in a better position to conduct the broad program of research; to accumulate necessary data on water supplies; to conduct training; and to administer enforcement activities and construction grants under the Water Pollution Control Act of 1956. If we are to move ahead successfully in the attack on water pollution, we must combine administrative, engineering, and technological skills at all levels of government. The creation of the new Division . . . represents a forward step in that direction." His concern in regard to public health leadership in this field was further reflected in his appearance before the Committee on Public Works of the House of Representatives.

Without question, he stated, water is about to become, indeed if it is not already, a critical national problem. He pointed to the facts that during the period 1950 to 1957, while our population increased 12-1/2 percent, total fresh water use increased by 57 percent. Whereas we now use 270 billion gallons of water per day, by 1980 we will need 600 billions—more than double our present requirements. These figures illustrate our great dependence on surface streams for public water supply, and for production of things we eat and wear and use. At the same time we must keep in mind the irreplaceable value of these waters for recreation and conservation of fish and wildlife. We don't stand a chance of meeting these requirements, Secretary Flemming said, unless we make marked progress in the direction of cleaning up our streams and keeping them clean.

NEW CONCEPTS IN PRESENTATION OF WATER RESOURCES DATA

Sanitary engineers interested in the graphical presentation of water resources data will want to obtain a copy of Section 1, Atlas of Illinois Resources, Water Resources and Climate. This is available from Mr. James F. Cannon, Superintendent, Division of Industrial Planning and Development, Capitol Building, Springfield, Illinois, at $2.00 per copy.

Water Resources and Climate was developed largely by the Illinois State Water Survey under the direction of William C. Ackermann. A great deal of thought and originality went into this report which covers runoff and stream flow, seasonal variations in hydrologic cycle, runoff, surface water supplies, sedimentation, ground water geology, industrial water pumpage, irrigation, mineral quality of water, precipitation, storms, temperatures, growing season, and water law. It was hoped that the sanitary quality of the State's water resources could be included, but circumstances prevented this. Directed primarily to the industrial representative, the Atlas provides an authoritative guide for the location of water supplies in which extensive quantitative and qualitative data have been resolved into simple, informative graphical presentations. There are to be some 10 sections in all covering minerals, forests, agriculture, transportation, and so forth.

PENNSYLVANIA POLLUTION CONTROL PUBLICATION REACTIVATED

"Clean Streams" a quarterly publication of the Pennsylvania Sanitary Board has been reactivated. The mailing list is being revised and persons interested in receiving this interesting report should send a request to the Sanitary Water Board, Pennsylvania Department of Health, P. O. Box 90, Harrisburg, Pa. The March issue contains an excellent discussion of sanitary engineering research needs by Shapiro and Weisberg of the University of Pittsburgh.

IDAHO REPORTS MAJOR PROGRESS IN WATER POLLUTION CONTROL

The Biennial Report of the Idaho Department of Health for 1956-1958 reports a record growth in the number of communities to provide sewage treatment facilities.

At the beginning of 1957, there were 22 communities, whose estimated population was 95,500, which had provided adequate sewage treatment. The total population then served by sewers in the state was about 260,000. Construction and authorized construction of both sewers and sewage treatment facilities during the two-year period raise the total sewered population in the state to some 300,000 persons, and makes sewage treatment facilities available to 205,000 of them. Percentage-wise, this amounts to an increase from about 37 percent at the beginning of 1957, to nearly 70 percent at the end of the two-year period. It marks a greater progress in sewage treatment than during any other period in Idaho's history.

The rapid growth of sewage treatment and water pollution control measures has been due largely to two factors. The probably impetus in the treatment construction program has been Public Law 660, passed by the 84th Congress, which not only provided more stringent interstate pollution laws, but which also provides federal grants-in-aid up to 30 percent of the cost of sewage treatment plant construction.

The second factor has been the extensive health education program aimed not only at pointing out the need for sewage treatment and the dangers of continued pollution, but also offering consultant service to city officials in the promotion of bond issues for such treatment facilities. Through the cooperation of the Idaho Department of Health's Engineering and Sanitation Section and the Health Education Service, the past binnium has been a milestone in water pollution control measures.

Some difficulties exist, however, and, even with the federal grant funds, several small communities are experiencing increasing difficulties in finding markets for the municipal bonds that are necessary to finance sewage treatment facilities.

With the growth of industry in Idaho—particularly food processing and wood processing—industrial wastes are producing acute problems in water pollution. The total pollution load from industry actually is greater than that from domestic sewage.

NEW ENGLAND INTERSTATE WATER POLLUTION CONTROL COMMISSION REPORTS SHARP UPSURGE IN SEWAGE TREATMENT PLANT CONSTRUCTION

The 11th Annual Report of the New England Interstate Water Pollution Control Commission reports real gains being made in the control of pollution from municipal sources. In 1958, New England treatment facilities were in operation or under construction to serve nearly 80 percent of the total population of sewered communities as compared to only 39 percent 10 years ago. The Commission cites several factors for the accelerating program of sewage treatment works construction. These include the untiring efforts of the State water pollution control agencies in pressing for the installation of treatment facilities, the availability of Federal advance loans for planning, and Federal and State grants for sewage treatment plant construction. The greatest stimulus to the construction program was said to be the Federal grants for sewage treatment plant construction as provided under Public Law 660 of the 84th Congress.

The progress in the installation of industrial waste treatment facilities was not found to be as impressive as in the case of sewage treatment works construction. The report said that, in general, the State water pollution control agencies have concentrated their efforts in pressing for industrial waste treatment only in those instances where pollution abatement programs are under way on classified waters or where nuisance conditions attributable to industrial waste discharges have occurred. As the municipalities fulfill their civic responsibility by constructing sewage treatment plants, industry is manifesting increased interest and cooperation in the pollution control programs.

SEWAGE TREATMENT PLANT DESIGN

If you have not yet obtained your copy of SEWAGE TREATMENT PLANT DESIGN you might wish to order one now. Available as ASCE Manual of Engineering Practice No. 36 from Society Headquarters in New York or as FSIWA Manual of Practice No. 8 from the Federation of Sewage and Industrial Wastes Associations Headquarters in Washington, the Manual can be obtained for $3.50 in paper binding or $4.50 in cloth binding by members of either organization.

The purpose of the Manual is to summarize and interpret contemporary practice in the design of sewage treatment plants. The joint ASCE-FSIWA Committee used as its criterion the incorporation of processes, equipment, and standards by engineers in designing plants during the 1935-1955 period. The Committee has not approved or disapproved of design practices, but has tried to report on the design practices generally adopted by engineers responsible for sewage treatment plant design. The Manual covers basic design considerations, general plant layout, plant pumping stations, screening, grit removal, flotation, flocculation, sedimentation, chemical precipitation, activated sludge, trickling filters, sludge pumping, sludge digestion and disposal, chlorination, chemicals, service buildings, materials and construction requirements, and safety considerations.

STATE SEWAGE TREATMENT PLANT DESIGN GUIDES

The Portland Cement Association has recently released a charted summary of design guides obtained from the State water pollution control agencies. This summary was published as a service to the sanitary engineering profession for the purpose of making this type of information readily available for reference use, comparison and improvement. It is not intended to replace design criteria or design procedures currently used by designers or to introduce any new criteria to be used by state or federal agencies in checking plans and specifications submitted for approval. Inquiries regarding "Sewage Treatment Plant Design Guides should be directed to the Conservation Bureau, Portland Cement Association, 33 West Grand Ave., Chicago 10, Illinois.

INDUSTRY HEAVILY FINED FOR FISH KILL

A fine of $154,770, largest in its history, has been levied by the Virginia Water Control Board against the American Viscose Company because of a mammoth fish kill which occurred in the Shenandoah downstream from the plant's waste discharge to the river.

The Water Control Board ruled on March 27 that "negligent discharge. . . of a substance or substances" from the Front Royal plant of the American Viscose Company had polluted the South Fork of the Shenandoah and caused the death of an estimated half a million fish within a distance of 35 miles downstream from the plant's waste outfall.

An official of the Virginia Commission of Game and Inland Fisheries gave the following breakdown of the fish killed: catfish, 265,000; smallmouthed and largemouthed bass, 35,000; sunfish, 170,000; sucker and carp, 30,000. The $154,770 fine represents the estimated cost of replacing the fish that were lost.

SEMINAR ON BIOLOGICAL PROBLEMS IN WATER POLLUTION

The Second Seminar on Biological Problems in Water Pollution sponsored by the Public Health Service's Robert A. Taft Sanitary Engineering Center was held April 20-24 at Cincinnati, Ohio. A total registration of 336 represented 44 states and six provinces of Canada. Subjects discussed included radioactive wastes, effects of pesticides, the lamprey control program,

oxygen requirements of fish, tainting of fish flesh, bioassays, and marine pollution problems.

Proceedings of the Seminar will be available from the Center approximately December, 1959.

STABILIZATION PONDS IN ILLINOIS

According to the Illinois Health Messenger, a publication of the Illinois State Health Department, Illinois is showing an increasing interest in the waste stabilization pond method of sewage treatment. There are now over 30 ponds in operation, and permits for an additional 21 ponds have been granted during the past year.

* * *

AIR POLLUTION

AIR POLLUTION CONTROL ASSOCIATION HAS NEW HEAD

Effective July 1, Harry M. Pier has resigned as Executive Secretary of the Air Pollution Control Association. He has held that post since June 1, 1957. Arnold Arch has been named to succeed Mr. Pier as Executive Secretary. Mr. Arch, who is currently President of APCA, will retain that office but give up his position as Director of the Air Pollution Control Department of Niagara Falls, New York.

NEW AIR POLLUTION CONTROL LEGISLATION

The Governor of Oregon has approved House Bill 519, as amended, relating to the State Sanitary Authority. This Act provides for the repeal of those Oregon revised statutes which established the Oregon Air Pollution Control Authority. The powers and duties of the latter are transferred to the State Sanitary Authority. The State Sanitary Engineer remains as Secretary of the Sanitary Authority.

New Legislation related to air pollution has been enacted during this year's sessions of three state legislatures. Idaho has created an Air Pollution Control Commission in the State Board of Health which has been authorized, among other things, to study air pollution problems; to adopt codes, rules and regulations; institute legal proceedings; and to secure injunctions. In South Carolina, a joint resolution of the State Legislature provided for the appointment of a committee to make a study of matters related to the peaceful use of atomic energy, the use of radioactive materials, and the control of air and water pollution. The Tennessee State Legislature created an Air Pollution Control Service in the State Department of Public Health to conduct a program of research and technical assistance, including the control of air pollution by local political subdivisions, individually or jointly.

The California Senate Finance Committee has unanimously approved a bill to require the State Health Department to set up statewide air pollution standards, and passage of this or a similar bill seems a certainty at this session of the Legislature. The California Legislature has already passed a bill which provides that the State Director of Public Health shall determine

by February 1, 1660, "the maximum allowable standards of emissions of exhaust contaminants from motor vehicles which are compatible with the preservation of the public health, including the prevention of irritation to the senses."

The U. S. Senate has passed Bill 441, which provides for extension of the Air Pollution Act through June, 1964. It also provides for an increase in the authorized annual appropriation, effective July 1, 1960, from $5 million to $7.5 million.

NATIONAL CONFERENCE ON AIR POLLUTION PROCEEDINGS OFF THE PRESS

The NCAP "Proceedings" are now off the press and can be obtained from the Superintendent of Documents in Washington, D. C. for $1.75. This 562 page book, PHS Publication #654, contains the formal presentations made to the plenary and group sessions of last November's National Conference on Air Pollution, plus a stenographic transcript of the discussion group and open forum meetings.

PUBLIC AWARENESS OF AIR POLLUTION

"Filth in the Air: The Damage It Does to Your Home and Your Health," a feature article by Ruth and Edward Brecher, is given top billing on the front cover of the April issue of REDBOOK, circulation 2,725,000.

"How Poisoned Air is Shortening Your Life," an article by Bernard Seeman, is similarly featured on the front cover of MECHANIX ILLUSTRATED for April, circulation 1,112,000.

"Finally! A Gasoline that BURNS CLEAN." That was the headline on recent full-page ads in color in Los Angeles and Long Beach newspapers which announced Tidewater Oil's Flying A 100-Plus, "a significant step toward the elimination of air pollution."

"SOS by California Women. A group of 150 Los Angeles women has formed a committee to Stamp Out Smog (SOS), is initiating a "right to breathe" campaign. Included are members of various other organizations which represent many thousands of persons, and the wives of men who are prominent in the fields of aircraft, motion pictures, and television. Among these are Mrs. Robert Cummings, wife of the actor and mother of five, and Mrs. Art Linkletter, wife of the well-known T-V personality and active in the National Charity League.

* * *

NUCLEAR ENERGY

RADIATION EXPOSURE

The Public Health Service reports that the only levels thus far developed for radiation exposure for the general population are those recommended by the National Committee on Radiation Protection and Measurements and the International Commission on Radiological Protection. Both groups recognize that the general population should be considered separately from industrial workers exposed to radioactivity.

The national committee on April 23 released a revision of its 1953 recommendations for industrial workers, but made no new specific recommendations for the general population. The international commission has made some tentative recommendations regarding radiation exposure for the general population which are being studied by the national committee.

The Public Health Service noted that the national committee in its statement of April 23 "considers that undue risks to the population will not be incurred by following current policies for a while longer, during which time it is hoped that methods may be established for a meaningful analysis and control of population exposure."

AIR FORCE RADIOLOGICAL HEALTH INDOCTRINATION

An indoctrination program and refresher course in principles of radiological health and actions required in the event of peacetime nuclear incidents was given, recently, to the sanitary and industrial hygiene engineers of the USAF Medical Service assigned to SAC, at Barksdale AFB, Louisiana. In attendance were 27 engineers of the Medical Service assigned to various SAC installations throughout the United States. Participating in the instruction, orientation exercises, and practical field monitoring were the Senior Industrial Hygiene Engineer, Office of the Surgeon, Headquarters, SAC, Colonel Alvin F. Meyer, Jr., USAF-MSvcC; Staff Sanitary and Industrial Hygiene Engineers of the numbered Air Force Commands of SAC, ZI, Captain W. D. Baber, USAF-MVvcC, Second Air Force, Captain Lynn R. Channell, Eighth Air Force, Major W. Z. Fluck, Fifteenth Air Force; and Staff Sanitary and Industrial Hygiene Engineer, 1st Missile Division, 1st Lt. John McCambridge. Refresher instruction on principles of nuclear physics, radiological health, instrumentation, and principles of monitoring was given. Representatives of the Air Force Special Weapons Center also participated in the demonstrations and practical monitoring exercises. Attending as observers from the Gunter Branch—School of Aviation Medicine were sanitary engineers Lt. Colonel Francis Johnson, USAF-MSvcC, and Captain Lawrence Jones, USAF-MSvcC.

CORRECTIONS FOR SEWAGE TREATMENT PLANT DESIGN MANUAL

Attention has been directed to two errors in the recently published ASCE Manual of Engineering Practice No. 36 "Sewage Treatment Plant Design," prepared in cooperation with the Federation of Sewage and Industrial Wastes Associations.

1. On the bottom of page 168, under Type I, the dosing rates should read "between 10 and 30 mgad" rather than "between 10 and 30 mgd."

2. In the middle of page 156 in the reference to Fig. 8, on page 157 within Fig. 8, at the top of page 157 in the reference to Fig. 9, and on page 158 within Fig. 9, the relationship $R = \frac{Q'}{Q}$ is incorrect. The correct recirculation relationship is $R = \frac{Q' - Q}{Q}$.

Readers are urged to notify either sponsoring organization as soon as possible if other errors are noticed. This request is made with the expectation that an errata sheet can be prepared and included in all copies sold after its issuance. Such errata sheets would also be available to those already in possesion of the Manual.

David H. Howells, EDITOR
Division Affairs Section, SED Journal
10126 Hereford Place, Silver Spring

ASSISTANT EDITORS

Professor Gilbert H. Dunstan
Dept. Civil Engineering
Washington State Institute of Technology
Pullman, Washington

Mr. Walter A. Lyon
Director, Division of Sanitary Engineering
Pennsylvania Dept. Health
P. O. Box 90, Harrisburg

Mr. James H. McDermott
Assistant Sanitary Engineer
Water Supply and Water Pollution Control
Program

Robert A. Taft Sanitary Engineering Center
4676 Columbia Parkway
Cincinnati 26, Ohio

ASCE MANUAL 36 NOW AVAILABLE

"Sewage Treatment Plant Design"

Several years of work by a joint committee of the Sanitary Engineering Division of ASCE and the Federation of Sewage and Industrial Wastes Associations have been culminated by the issuance of a manual on "Sewage Treatment Plant Design." In this manual the joint committee has summarized and interpreted current practice in the design of sewage treatment plants. The committee does not attempt to approve or disapprove the practice, but merely reports on what is being done.

Copies of the new ASCE Manual (No. 36) can be obtained from ASCE by use of the following coupon. The list price is $7.00 and ASCE members are entitled to a 50% discount.

Early Transactions Volumes Obtainable

The feasibility of reproducing the first ten volumes of ASCE TRANSACTIONS (1872-1881) has been studied. It has been decided that these historic volumes could be reproduced at a cost that would permit a top price of $150 for the ten-volume set. If more than 100 engineers, or libraries, indicate an interest in obtaining such a set, the project will be undertaken. If the endeavor is successful, other rare volumes of TRANSACTIONS will be reprinted.

Engineers interested in obtaining the ten-volume set should write to the Executive Secretary of ASCE, 33 West 39th Street, New York 18, N. Y.

----------CUT HERE----------

American Society of Civil Engineers
33 West 39th Street, New York 18, N. Y.

Please send me . . . . . copy(s) of Manual 36. Enclosed is my remittance of $. . . . . My ASCE membership grade is . . . . . .

_____
Print Name

_____
Address

_____
City Zone State

. . . . of M36